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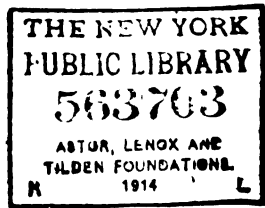
WITH OTHER
SELECTED AND ABSTRACTED PAPERS.

VOL. CLXVIII.

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J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

- Vol. clxvii, p. 259, line 4, *after* "possible," *insert* "not."
 " " p. 315, Table, heading of col. 6, *after* "Coal" *insert* "Light."
 " " " " col. 6, line 2 from bottom, *for* "2s. 9d." *read* "2s. 11d."
 " " p. 317, Table, *after* "Main excavation," *insert* "driven."
 " " p. 462, line 8 from bottom, *for* "boot" *read* "boat."
 " " p. 478, " 2 " " *for* "last year" *read* "1905."

THE
INSTITUTION
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CIVIL ENGINEERS.

SESSION 1906-1907.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

18 December, 1906.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President,
in the Chair.

(Paper No. 3589.)

“Mechanical Considerations in the Design of
High-Tension Switch-Gear.”

By HENRY WILLIAM EDWARD LE FANU, M. Inst. C.E.

CO-ORDINATELY with the increase in the output and pressure of electrical machinery during the last 15 years, a remarkable development has taken place in the general design and arrangement of the high-tension switch-gear which controls such machinery. The result of these years of experience has been to establish several distinct types of gear, each of which has, under certain conditions, proved fully satisfactory in practice. The tendency of the mechanical design of modern switch-gear has been to confine accidents, resulting from defective insulation, short-circuits, mistakes in manipulation, etc., within the smallest possible limits, and so to prevent the consequences of such accidents from spreading to adjoining apparatus and causing serious breakdowns.

PARTITIONING OF HIGH-PRESSURE APPARATUS.

The first step in this direction was taken by Mr. S. Z. de Ferranti, M. Inst. C.E., who recognized at an early date the necessity of partitioning all high-tension apparatus, and of thereby preventing accidental contact between the various parts under tension. He further appreciated the advisability of a thoroughly systematic arrangement of all apparatus, connections, bus-bars, etc. The Ferranti cellular switchboard was for many years the only example embodying these principles.

In earlier switchboards, in order to avoid arcking in the air-break
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switches, the different poles were protected by plates of asbestos, slate, or marble. Similarly, the bus-bars were separated throughout by slabs of slate or marble, and were supported upon double porcelain insulators mounted on a marble base. In order to separate more effectually the apparatus belonging to the various units or panels, and to be able to isolate them for repairs in case of breakdowns, heavy marble or slate slabs were inserted between the adjoining panels, or masonry walls built into the framework of the switch-board were employed. Any metallic framework, being liable to cause dead short-circuits in case of breakage of insulators, has been dispensed with altogether in more recent designs.

The adoption of the oil-switch, instead of the unreliable air-break type, marks another step in the successful control of large amounts of energy under the most severe conditions of practice. The old safety device—the fuse—was also replaced by the circuit-breaker,¹ an apparatus designed to operate automatically on overloads in the case of feeder-circuits, and on reverse currents in generator-circuits.

With switch-gear of large capacity the whole system is protected, and, whenever possible, apparatus and cabling of different polarity are separated by masonry walls, or by heavy barriers of concrete, slate, or marble. The earlier practice of combining on the same framework all switch-gear, high- and low-tension, was soon given up, and the necessary separation of these parts brought about the introduction of remote control for the high-pressure section.

As the capacity of power-stations and the pressure employed increased, methods of carrying out the foregoing principle developed. Certainty of operation and the safety of the operator had to be provided for; but it was also essential that all parts of the gear should be easily accessible for inspection and repairs, and that continuity of supply, in case of breakdown of any one machine, apparatus, or feeder, should be adequately assured.²

The object of this Paper is to describe, from a mechanical point of view, examples of high-tension switch-gear, which have successfully borne the test of practice. For simplicity, only three-phase gear has been considered, but the same principles apply, with slight modifications, to single-phase or two-phase installations. As the

¹ In his "Notes on Three-Phase Switch-Gear," *Engineering*, vol. lxxvi (1903), p. 409, Mr. A. C. Eborall treated very fully the question of the replacement of fuses by oil circuit-breakers.

² Mr. E. W. Rice, Jun., in 1901 laid down several fundamental rules concerning the protection of apparatus in fire-proof cells, the arrangement of circuits, etc., which form practically the basis of all modern high-pressure switch-gear. See his Paper "The Control of High-Potential Systems of Large Power." *Transactions of the American Institute of Electrical Engineers*, vol. xviii, p. 407.

development of the various methods of controlling the energy in power-stations of large capacity is best shown in contrast with the gear for smaller plants, a short account of the latter will first be given.

EXAMPLES OF SWITCH-GEAR FOR STATIONS OF SMALL CAPACITY.

To fulfil the primary condition—the separation of high- and low-tension apparatus—all this switch-gear was designed for remote control, either mechanical or electrical. Figs. 1, Plate 1, are the section and plan of a switchboard for the distribution of energy, for lighting and power, in a colliery. There are two three-phase alternators, each of 300 kilowatts, 3,000 volts, with direct-coupled exciters; several outgoing high-tension feeders; and one step-down transformer for feeding the local power-circuits at 500 volts. The local lighting-circuits are fed from the exciters.

The high-tension compartments are placed against the wall of the building, the operating-panels being mounted on a gallery about 3 feet above the machine-room floor, and about 4 feet in front of the masonry compartments, leaving a free passage between. The girders of the switchboard-gallery form one structure with the framework of the operating-panels. The flooring of the gallery is either of chequered plating or of wood lined on the lower side with asbestos, or other fire-resisting material.

The high-tension cables coming from the alternators enter the compartments at the bottom, are connected to the various instrument- and relay-transformers, the circuit-breakers, and panel section-switches, and are finally joined to the bus-bars, which are placed above the passage between the compartments and the operating-board. For the feeders the reverse order must be taken. In order to simplify the arrangement of apparatus and wiring, there are nine low-tension panels, so arranged as to give complete separation according to the nature of the current controlled by them. Facing the board, these low-tension panels are disposed from left to right thus:—

(a) Continuous current. One panel for the local lighting-circuits one panel for the two direct-driven exciters.

(b) Low-tension alternating current. Two panels for the two alternators, two for the four high-tension feeders.

(c) Medium-tension alternating current. One panel for the low-tension side of the power-transformer, and two for four feeders branched from the transformer.

(d) A small panel mounted on a swivel bracket contains the synchronizing-instruments.

Eight high-tension compartments are next to the

alternators, four for the feeders, one for the synchronizing-transformer and the multiple-way switch for the electrostatic ground-detector, and one for lightning-arresters, since several of the feeders are overhead.

In order to reduce the width of the operating-panels to the minimum just necessary for all the low-tension gear, it was not possible to keep the high-pressure compartments in line with the corresponding low-tension panels without undue cramping of the high-tension apparatus, or without augmenting unnecessarily the size of the operating-panels.

The compartments were therefore displaced relatively to the panels, the only difficulty encountered being the disposal of the circuit-breaker driving-rods. The complication entailed was, however, more than outweighed by the economy gained through the reduction in length of the operating-panels.

The high-tension compartments are formed by brick walls coated with cement, having a total thickness of about $5\frac{1}{2}$ inches, and are covered in at the top by cement slabs 2 inches thick (Figs. 1, Plate 1). Each compartment is subdivided into three cells by similar barriers. These smaller cells serve for the reception of:—

- (a) The cable-dividing boxes and the instrument-transformers with their fuses.
- (b) The circuit-breakers.
- (c) The panel section-switches.

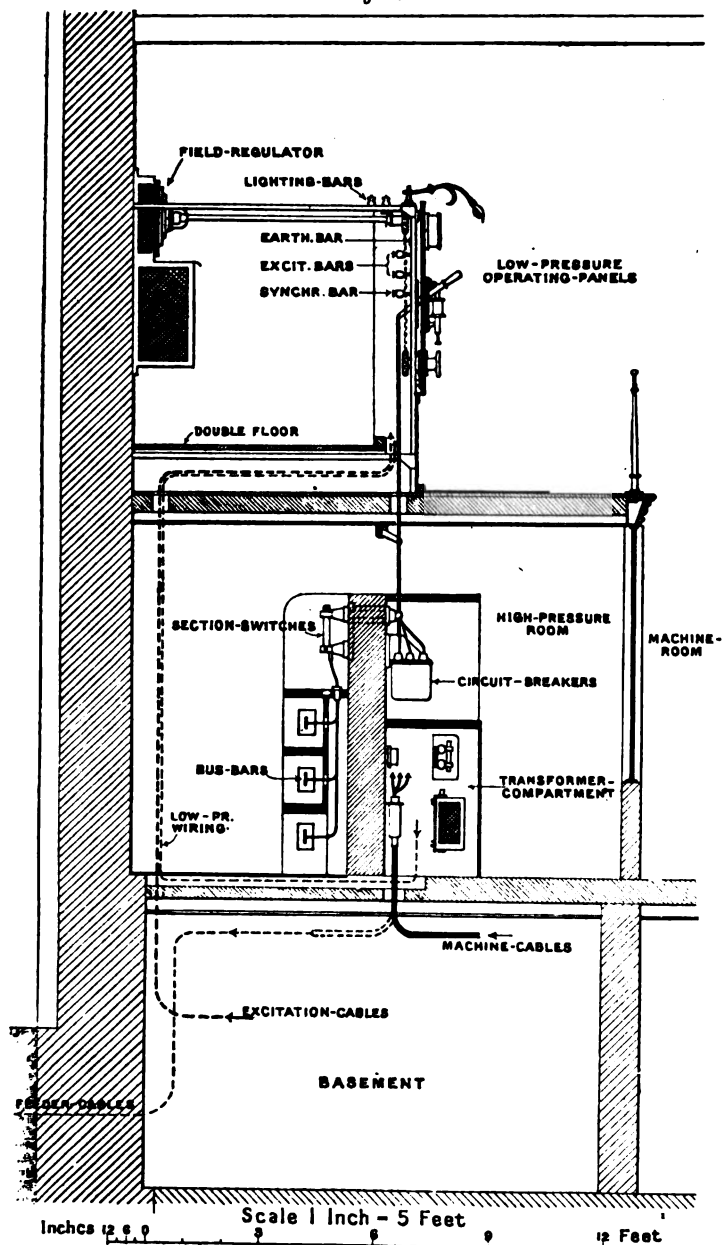
The high-pressure bus-bars are doubly insulated by heavy porcelain insulators, and are separated by slate plates, thereby preventing risk of accidental short-circuits.

The driving-rods of the switches are mounted below the bus-bars, and the low-tension wiring is carried under the switchboard-gallery to the operating-panels. As shown in Figs. 1, the various field-regulating and discharge resistances, and the low-tension apparatus for the excitation-, lighting-, and power-circuits, are placed at the back of the low-pressure board. As in mining installations it is not usual to allow any live parts to be mounted on the front of the board, a special type of switch, with contacts behind the panels, was provided.

The high-tension circuit-breakers are designed on the "free-handle" principle, rendering it impossible to keep the switch closed on a short-circuit. Two breaks are provided per pole, and the opening of the switch is assisted by a powerful spring. The oil-tank into which the contacts plunge is divided by insulating partitions into three compartments, to prevent arcking from pole to pole. All contacts terminals are carried on heavy corrugated porcelain insulators.

Design of switch-gear for a station of 3,000 kilowatts capacity, machine units of 750 kilowatts, is shown in section in Fig. 2.

Fig. 2.



SECTION THROUGH HIGH-PRESSURE SWITCHBOARD (6,500 VOLTS, 750-KILOWATT UNITS).

The high-tension gear is underneath the switchboard-gallery (or in the basement), on either side of a strong brick wall. The bus-bars are mounted in separate horizontal concrete ducts, and with the section-switches above are very accessible. The connections from the section-switches to the bus-bars are laid in vertical recesses cut in the brick wall.

As the number of units—alternators and feeders—was large in this case, and as only one series of bus-bars was used, the feeder-panels and compartments were arranged symmetrically on either side of those of the machines, and the bars were divided by switches into four sections. Thus, in case of a breakdown on any section of the bars, only one-half of the feeders would be put out of service. Each sub-station is fed by at least two feeders, and continuity of supply is assured by arranging that no sub-station is supplied by feeders branching from the same section of bus-bars.

The field-regulating resistances are placed against the wall of the building, behind the operating-panels, leaving the space at the back of the panels free for the low-tension connections and smaller apparatus. The secondary wiring between the compartments and the low-tension board, as well as the exciter-cables, are brought up against the wall of the building and laid between double flooring behind the operating-panels. Where possible it is better to fix this wiring directly underneath the switchboard-platform.

HIGH-PRESSURE CIRCUIT-BREAKERS.

The character of a design for switch-gear is practically determined by the circuit-breakers. In the equipment just described the normal rating of the circuit-breakers is 800–1,000 kilowatts, at 6,500 volts. For larger capacities a radically different type becomes essential. The length and quickness of break must be increased to ensure opening the circuits with certainty under the most unfavourable conditions. Better protection of the different poles from each other, as well as from the metallic supporting frame, must be provided for.

The circuit-breaker shown in Figs. 3, Plate 1, has six breaks and is rated at 3,000 kilowatts, 10,000 volts. Four steel columns rising from a cast-iron bed-plate support a strong cast-iron frame of U section, on which the driving mechanism is mounted, and to which, on the lower side, the main contacts are fixed. A stout plate of soapstone is interposed between these contacts and the frame. The fixed contacts, which are immersed in separate oil-tanks placed below the frame, are held in heavy porcelain insulators of the corrugated

type and are bridged by movable gun-metal knives carried by three vertical rods, from which they are insulated by porcelain and paper bushings. These rods, carried by a cast-steel cross-bar of rectangular section, are suspended by links and connected by levers to a horizontal spindle, so that a straight-line motion is imparted to the system of movable contacts. In order to leave the incoming and outgoing cables completely free, the operating- and tripping- magnets are placed on one end of the frame. The operating-magnet is mounted on four steel columns, threaded at their ends, so that the height of the magnet may be adjusted. The tripping-magnet is fixed on a special support bolted to the frame.

As it is of importance to be able readily to inspect the contacts, the three oil-tanks rest on a cast-steel base supported on two threaded steel columns, and, by means of a reversible ratchet fixed underneath the base-plate, they can be lowered or raised. The tanks, which are held in place by pressing them up against the circuit-breaker frame with the ratchet mechanism, are made of sheet metal and are lined with wood or an insulating and non-inflammable compound, and an oil-level gauge and drain-cock are fixed to each of them. To prevent contact between the phases, in case of a breakdown on one pole, heavy slabs of soapstone or slate are placed between the tanks and between these and the switch-frame. The vertical plates fit into grooves and can be moved out of the framework should occasion arise. The horizontal slabs are fixed to the frame.

The contacts of the circuit-breaker are of the spring-wedge type and of a heavy design necessary for mechanical strength. To avoid arcking between the main contacts, the circuit is broken by parallel auxiliary contacts after the main contacts have already opened.

The porcelain insulators carrying the copper rods to which the contacts and terminals are fixed are designed with large surfaces to prevent leakage. Should these insulators break, arcking to the frame is further prevented by a sheathing of "micanite" and paper placed around the rods.

The circuit-breaker is operated in the following manner:—For closing it, the driving-magnet is energized and its core lifts, by means of a connecting link and toggle-joint, an arm which actuates the horizontal spindle, and thus raises the movable contacts into the closed position. To prevent the core of the operating-magnet from falling when the current is taken off, one end of the link forming the toggle-joint engages a spring catch. The whole weight of the mechanism is taken up by the toggle-joint, and only a small pressure remains upon the catch. For opening the switch the tripping-coil is magnetized, whereupon its core, as it lifts, transmits through a lever

and tripping-rod a hard blow upon the interlocking catch. This blow disengages from the driving mechanism the whole system of movable contacts, which, in falling, opens the circuit. As the weight of the movable parts is considerable, the break is quick, and it has not been found necessary to aid the action of gravity by springs. In case the tripping-coils should fail to act, an auxiliary mechanical release catch is fitted to the switch. It is undesirable that the attendant should be obliged to enter the high-pressure room to manipulate this catch, hence it should be operated by a steel wire or cable from the operating-board or columns. This reserve release is of great importance, as the failure of a switch to open may be attended with the gravest results.¹

The upward movement of the mechanism is limited by a stop arranged on the toggle-joint, and its fall is taken up by steel springs. On opening the switch the driving mechanism and magnet-core remain suspended until the catch holding the toggle-joint is released by one end of the falling cross-bar.

As will be seen from the foregoing description, the design of the operating mechanism is based on the "free-handle" principle, for the mechanism of the circuit-breaker proper is quite independent of the driving-gear. There is, in fact, no connection between the two, save the interlocking catch, which, when the switch is closed on a short circuit, is released as soon as the auxiliary contacts close the circuit.

The current taken by the operating-magnet is about 46 amperes at 45 volts (continuous current), and by the tripping-magnet, about 2 amperes at 45 volts (continuous current). As the magnet-coils are in circuit only for a short time during each operation, they may be wound for a high current-density. For security under these conditions it is necessary to make it impossible for the operator to keep the current on the magnet and so burn out the winding, as the damage thus caused might escape detection until the switch had again to be closed, when failure to operate would cause considerable inconvenience. To avoid this, the control-switch is designed in such a manner that the operator has only to turn the handle through an angle slightly larger than 180 degrees, thereby compressing a spring, which during the second half revolution completes the movement of the controller-barrel independently of the operating-handle. The time during which the current must flow in order to ensure the closing of the circuit-breaker is regulated by a dashpot. A simpler arrangement, adequate in many cases, consists of a switch provided with a spring, so

¹ In large power-stations, where the group switches afford additional security this auxiliary release is unnecessary.

that when the operator releases the handle the control-switch opens.

In most cases it is advantageous, from considerations of space and economy, to replace the bed-plate and supporting columns of these switches by a masonry structure.

This method has been employed for years with great success by the General Electric, British Thomson-Houston, and Westinghouse companies. Each phase is built into a separate cubicle, accessible from the front by removing a sheet-metal door. The terminals are completely separated from the mechanism, and, with the doors of the cubicles closed, are inaccessible from outside. The switch consists of two entirely separated parts, the electrical mechanism, which is completely enclosed in the masonry structure, and the operating mechanism, which is placed above the cells and is easily accessible (Figs. 15, Plate 2). The circuit-breakers built by the Thomson-Houston Company are controlled by a small motor, whereas the Westinghouse Company employs solenoid control.

A novel feature in the design of such apparatus has been introduced by Messrs. Ferranti, who avoid the use of all intermediary levers and shafts in the driving-mechanism. The great difficulty in solenoid control is to obtain a long stroke of the core combined with the necessary lifting-power. Messrs. Ferranti overcome the difficulty by dividing the solenoid into two portions, an upper and a lower, each provided with a separate plunger (Figs. 4, Plate 1). The lower plunger is rigidly attached to the moving contact-system. The upper plunger is concentric with, but not directly attached to, a rod which forms virtually a prolongation of the lower plunger. The upper end of this rod is provided with a collar, which rests upon the top surface of the upper plunger when the switch is in the open position. Both solenoids are energized together, the first half of the stroke being effected mainly by the upper plunger being drawn within its solenoid to its full extent, and carrying the switch mechanism with it, by virtue of the collar. By this time the lower plunger has been brought into a favourable position to be acted upon by the lower solenoid, and the second half of the stroke is completed. By this device a very powerful long-pull electromagnet is obtained, giving a stroke of 10 inches with a minimum pull of 180 lbs., and a maximum pull at the end of the stroke of 400 lbs.

This switch is held in the closed position by the usual toggle-joint, thus preventing it from opening in consequence of vibration. There are two other distinguishing features about the Ferranti circuit-breaker which are of great importance in respect of reliability in opening circuit. The first consists in the employment of insulating

slabs surrounding the rods to which the moving contacts are attached. These slabs slide down into the tanks, each tank being thus divided into two separate compartments for the purpose of minimizing the risk of under-oil arcking. The second and more important feature has reference to the oil-space of about $\frac{3}{4}$ inch, between the walls of the tank and the insulating lining. When the circuit is broken under oil, the arc which forms drives the oil from the immediate neighbourhood of the contacts, thus considerably decreasing for the time the dielectric resistance between each pole and the tank or earth. The layer of oil, however, between the tank lining and case, remains quite undisturbed, and maintains the dielectric resistance during the break.

It is desirable, in order to avoid difficulties of erection when masonry support is used, that all apparatus, such as circuit-breakers, section-switches, rheostats, etc., should be, as far as possible, self-contained.

REMOTE CONTROL FOR HIGH-PRESSURE CIRCUIT-BREAKERS.

Remote control for the circuit-breakers may be electrical or mechanical, or a combination of both systems. The choice depends to a certain degree on the local conditions. Where it is possible to establish a short and direct drive, it seems wisest to employ mechanical control, and especially for feeder circuit-breakers which need not be often manipulated. Manual control has this advantage over electrical, that no auxiliary source of energy is required and there are no troublesome control-switches and connecting cables. Where electrical control is adopted, provision should be made to close the circuit-breakers mechanically by an auxiliary lever, in order to avoid the inconvenience of leaving one of the generating-units or feeders idle while in search of a fault in the control-circuits or during repairs on the operating-magnet or motor of the corresponding switch. Electrical control becomes, of course, imperative where space is limited, and where a large number of circuits have to be dealt with.

The various parts constituting the mechanical driving-gear should be of strong and simple construction. Contrary to the ordinary practice with small circuit-breakers, in which the driving mechanism is fixed directly to the steel framework of the operating-panels, in the case of large circuit-breakers the heavy cast-iron supports, with their levers, should be placed in front of the corresponding panels, and bolted to the floor-girders. This arrangement prevents the communication of vibrations to the operating-panels when manipulating such heavy switches. The main driving-lever is provided with a

smaller auxiliary lever, which engages a catch in both the open and the closed position. The main lever is thus securely held in position and is prevented from being displaced through inadvertence.

When a circuit-breaker which is designed on the free-handle principle opens automatically, or when it is opened by closing the tripping-coil circuit, the driving mechanism remains in the closed position, and has to be brought back by hand, in order to be reset for a fresh operation. This independence of the driving mechanism from the movable part of the circuit-breaker proper is very important for the rapid opening of the switch, as no heavy pieces have to be put in motion save those of the switch itself. In this respect, therefore, there is nothing to choose between electrical and mechanical control.

With remote control, an optical indicator, mounted on the front of the operating-panels, becomes necessary for each circuit-breaker. Such an indicator consists of two differently-coloured lamps, of which one or the other should be always alight, in order that the operator may tell by a glance at the board which of the circuit-breakers is closed and which open. It is useful also to provide an alarm-bell, which rings when one of the generator- or feeder-switches opens automatically.

A small "contactor" is coupled to the movable part of the circuit-breaker. Its function is two-fold. It serves to make and break automatically the circuits of the signal-lamps and alarm-bell, and to open the discriminating and overload relay-circuits. These relays are delicate instruments, and, if they are not provided with carbon contacts, it is necessary, on account of the small arcs which occur between their contacts on opening, to break circuit with a contactor. The contactor will be seen on the right of the circuit-breaker in Fig. 3, Plate 1. *Fig. 5* is a general diagram of connections of electrically-operated circuit-breakers.¹

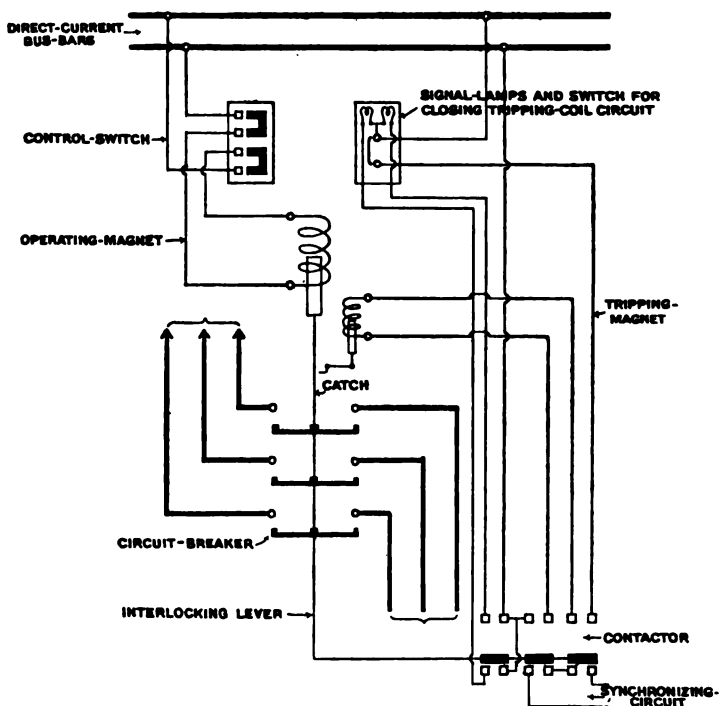
¹ It is not within the scope of this Paper to enter into a description of the relays used in connection with these circuit-breakers, a subject which has been fully discussed in a Paper by Mr. L. Andrews, "High Tension Switch-Gear," *Journal of the Institution of Electrical Engineers*, vol. xxxiv (1905), p. 438.

With regard to the type of relay to be used, Mr. Andrews sums up in the following rule:—

"Where current is fed into bus-bars from a number of sources of supply connected in parallel, discriminating cut-outs only should be used. Where current leaves bus-bars to supply a number of feeders, transformers, motors, or distributors, excess-current cut-outs only should be used."

Although Mr. Andrews pointed out this simple and really self-evident maxim many years ago, the importance of the choice in the protection of machines and feeders has not as yet been universally realized, and it is not unusual to find the time-honoured fuse, or a combination of reverse and overload relays, doing service

Fig. 5.



CONNECTIONS FOR ELECTRICALLY-OPERATED THREE-POLE OIL CIRCUIT-BREAKER
(TWO BREAKS PER POLE).

(The connections are shown for the open position of the switch.)

in alternator-circuits, or even overload relays without time-limit attachment in the machine, and fuses in the feeder-circuits.

There is one other point with respect to these protective devices which is often neglected on account of the higher initial cost of the apparatus. Three-phase circuits are usually considered amply protected by the insertion of protective devices in two phases only. Under ordinary circumstances this may, of course, suffice, but account should be taken of the fact that a relay or its transformer may break down, or some fault develop in the connections between the circuit-breaker and the relay or between the latter and its transformer, thus rendering one pole of the relay inoperative, and the whole device illusory, without even the slightest warning to the switchboard-attendant. For this reason it is advisable to arrange for a certain reserve and instal three-pole relays in both machine- and feeder-circuits. The extra cost and complication entailed is trifling compared with the great saving incurred on the outbreak of an accident. When the neutral point of the alternator is connected to earth, there is, of course, no alternative and relays must be placed in the three poles.

ARRANGEMENT OF COMPARTMENTS FOR HIGH-PRESSURE APPARATUS.

Referring to the classification of the high-tension compartments on p. 4, it can now be understood that these heavy circuit-breakers require correspondingly spacious compartments. The high-tension gear must be placed in different galleries on account of the larger head-room necessary. A different method of disposing the compartments must also be adopted, because if they were placed in one row the total length of the masonry structure could not be kept within reasonable limits. To this end the compartments are placed alternately on either side of a central wall, so that those belonging to panels Nos. 1, 3, 5, etc., will be on one side of the wall, and those of panels Nos. 2, 4, 6, etc., on the other side. Distributing the high-tension compartments back to back in this manner has the further advantage of reducing the length of the bus-bars by one-half, and also the number of the supports, which are practically the only weak parts in a bus-bar system. There is, however, the inconvenience that the cables leading to or from the circuit-breakers pass between these and the central wall. This should be avoided if possible, as no cables whatever should be tolerated near the switches, with the exception of those necessary for connecting up. There are two ways of overcoming the difficulty. The first is to arrange for vertical trenches in the wall and to close them in front by cement or slate slabs: in the second, the cables are led up to the proper height on the other side of the wall in a separate compartment placed between two adjacent circuit-breaker cubicles. The latter method necessitates a longer masonry structure, but it has the advantage of leaving all cables free for inspection. The circuit-breakers shown in Figs. 15, Plate 2, lend themselves to an ideal cabling scheme, as the conductors enter and leave at the bottom of the switch and are taken in covered-in trenches to the neighbouring compartments, thereby leaving the operating mechanism completely free of all parts under tension.

In the St. Denis power-station¹ the circuit-breakers are disposed in two rows, but, instead of being placed back to back against a central wall, each row is mounted against a separate wall, leaving a passage between. Facing the engine-room in the first

¹ This power-station, of a total capacity of about 70,000 kilowatts, has been designed by the Société d'Électricité de Paris, and the switch-gear for the extensions is being executed by the Ateliers de Constructions Électriques de Charleroi.

row are the machine-, bus-junction, and feeder-group switches, whereas the second row contains only the feeder circuit-breakers. All cables leading to and from the switches are brought up on the back of the walls, and, after being connected to the instrument- and relay-transformers, pass through porcelain bushings to the switch-terminals.

With the back-to-back arrangement, when mechanically-operated circuit-breakers are employed the width of the operating-panels is preferably half that of the compartments. In this case a straight and direct drive between the operating-levers in front of the low-tension board and the circuit-breakers becomes possible, and as the panels and corresponding compartments face each other, the low-tension wiring may be arranged symmetrically.

EXAMPLES OF SWITCH-GEAR FOR STATIONS OF LARGE CAPACITY.

The switch-gears represented in Figs. 14, Plate 2, and Figs. 6, Plate 1, are typical examples for capacities of 10,000 kilowatts and 20,000 kilowatts respectively, the generating-units being for 1,500 kilowatts and 3,000 kilowatts, normal rating, at 6,500 volts.¹ Apart from certain minor differences, these two types are designed on the same lines. The high-tension gear is placed in three rooms; the transformer and discharger room, the circuit-breaker room, and the bus-bar room. In the first type the operating-board is placed in a separate chamber above the bus-bar room, which chamber is open on the machine-room side and provided with a gallery. The main circuit-breakers are all fitted with electro-magnetic control, because of the difficulty of disposing the driving-rods and levers for mechanical control. In the second type the panels are placed on a gallery, level with the floor of the circuit-breaker room, and the machine circuit-breakers are arranged for electrical control, whereas those for the feeders are controlled manually. The difference in the two examples is due mainly to the design of the buildings, but on the whole the second arrangement may prove more practical, as the important apparatus is within reach of the switchboard-attendant.

These two cases were designed with a view to underground feeders only, consequently the high-pressure bus-bars are situated in the uppermost part of the high-pressure galleries. It was only when

¹ The switch-gear for both of these power-stations was carried out by the Ateliers de Constructions Électriques de Charleroi, the second to the order of Messrs. Witting, Eborall and Company for the Port Dundas lighting-station in Glasgow.

the buildings were in an advanced state that overhead feeders were added in the first installation (Figs. 15), and cable connections had to be provided leading from the compartments in the basement to the lightning-arrester chamber, where the aerial lines start. For overhead feeders it is better to run the cables from the machines in a vertical line through the machine-apparatus and circuit-breakers to the bus-bars, and thence through the feeder-transformers and switches to the lightning-arresters; but on account of the line-protecting devices an extra gallery has to be added.

In dealing with these large capacities, it is imperative to adhere rigidly to the system of complete separation of the different poles. Each of the main compartments is therefore partitioned by strong vertical slabs of slate, soapstone, or ferro-concrete,¹ into three narrower cells. Wherever possible, the instrument-transformers ought to be further isolated from each other by horizontal barriers of similar material. The high-pressure bus-bars into which all the energy generated in the station flows, and from which it branches into the various distributing feeders, must be protected in the most careful manner. They are therefore mounted in long horizontal masonry conduits (Figs. 6, Plate 1, and Figs. 14, Plate 2), a separate structure being provided for each set of the duplicate or ring bars. This permits of cleaning or repairing one set without danger to the workman from the other set being alive. Unless placed in a special chamber by themselves, the bus-bars should be protected on all sides. They can be closed in on the front by armoured glass screens, fitted with handles, so that the screens may be easily removed; or, as is usual in American practice, they may be completely enclosed within the masonry structure, leaving doors for inspection opposite the supports only (Figs. 15, Plate 2).

As it is necessary, for cleaning or repairs, to isolate the compartments belonging to any one generator or feeder, section-switches are inserted between the oil circuit-breakers and the bus-bars. These section-switches are of the ordinary knife pattern, mounted on heavy, corrugated, porcelain insulators, and fixed to a slate or marble base as shown in Figs. 1, Plate 1. Unless very special precautions for insulation and earthing are taken, the contacts of section-switches should not be mounted on a common metal base-plate. The base-plate should be of some insulating material, to prevent the isolated apparatus from coming into contact with live parts, in case one of the porcelain insulators should break.

¹ Ferro-concrete has the advantage over the other materials of giving a maximum of strength for the same thicknesses.

The section-switches are placed in separate compartments, either above the main circuit-breakers or behind the wall against which the bus-bars are fixed. In this latter case, the porcelain insulator supporting the bus-bar serves at the same time as a support for one contact of the section-switch. A copper stud passing through the insulator from the bus-bar supplies the necessary connection. Such an arrangement greatly simplifies the structure and reduces the cost of the apparatus and the cost of erection. The bus-bars are fixed by clamps, and as the drilling of holes is therefore unnecessary, any discrepancy in the distances between the supports need not be reckoned with.

ARRANGEMENT OF HIGH-PRESSURE CIRCUITS.

Simultaneously with the increase in capacity of the plant, greater elasticity of control becomes necessary, and the subdivision into sections is developed in such a manner that each of the powerful generating-units, with a certain number of feeders, constitutes a distinct group. These groups must, however, be capable of inter-connection to assure continuity of supply in the event of a breakdown.

The bus-bars are often arranged either in duplicate or on the ring-main system, and subdivided into independent sections. In the former case, all machines and feeders can be connected, by duplicate sets of section-switches, to both series of bars, so that no circuit need stand idle when a breakdown on one set of the bars occurs, or when cleaning or repairs are necessary. In a ring-main system where the various circuits are connected to one side only of the bars, and these are divided into several sections, any circuits connected to an isolated section must necessarily remain idle. The two systems may, however, be advantageously combined, especially when dealing with a large number of generators and feeders, as the total number of circuits can then be subdivided into independent groups. This provides additional security against a general shut-down of the station, consequent upon the failure of any one group. An example of such a combination of systems is shown in Figs. 6, Plate 1.

The same objection that holds against the obsolete ring-main system of steam-pipes for power-station work ought to be applied to the ring-main system of high-pressure bus-bars. In stations of small capacity it is from its comparative simplicity often desirable, especially as it has the additional advantage that the total outgoing energy can be easily measured; but it is not recommended for stations of large capacity. Further, this system requires the greatest length and weight of copper bars and the most masonry, and all

combinations have to be effected with the section-switches in the bus-bars, which operations are always attended by a certain amount of risk.

When the number of feeders becomes very considerable, as for instance in the cases of the Main Rapid Transit Generating-Station in New York, and the Lot's Road Generating-Station in Chelsea¹ (about seventy feeders in the latter case), it becomes imperative to dispose the feeders in groups, each with their own separate bars, these groups in their turn being branched off the main bus-bars. The two cases differ, however, with regard to the system of bars. In the first instance, which may possibly give a wider range of action but is slightly more complicated, duplicate bars are used (*Fig. 7*), whereas in the second case, only a single line of main bars is employed, but these are subdivided, each section being fed by two alternators (*Fig. 8* and *Fig. 15*, Plate 2). For paralleling and for facility of operation the main combinations are made by means of electrically-controlled non-automatic oil-break switches.²

The arrangement shown in *Fig. 8* represents perhaps the nearest approximation to finality in subdivision, namely, the "Complete Unit" system, as advocated by Messrs. Merz and McLellan in the Paper³ read by them before the Institution of Electrical Engineers in April, 1904. According to this system the entire power-house is sectioned into several absolutely self-contained units from boiler to feeder-cable, capable of interconnection only at the main steam-collector and at the main bus-bars. The arrangement of circuits in the St. Denis power-station is similar to that shown in *Fig. 8*, with the difference that there is only one machine per section and that tie-switches are provided between the feeder group bus-bars. This latter additional security was necessary in order to ensure continuity of service in case of one of the group-switches breaking down, more especially as many of the sub-stations are supplied by one feeder only.

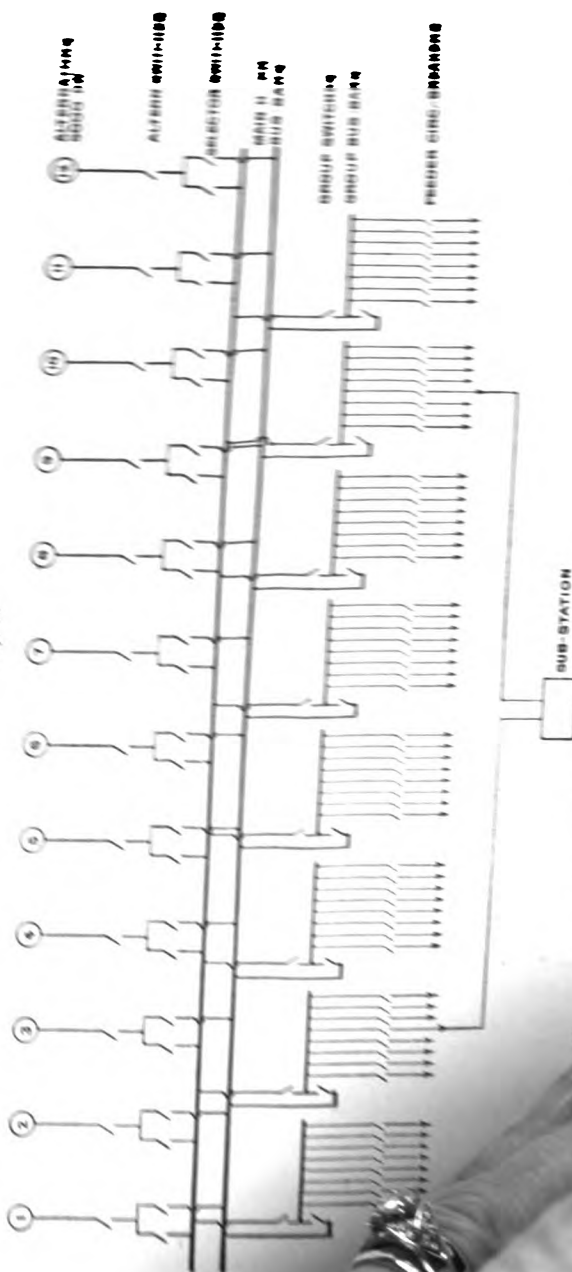
To sum up, the system of bus-bars may differ greatly with the various conditions resulting from the character of the plant, the

¹ The switch-gear in the first case was carried out by the General Electric Company, of Schenectady. In the second case by the British Thomson-Houston Company.

² The question of the use of group-switches in large power-plants has been dealt with by Mr. L. B. Stillwell, in a Paper on "The Use of Group-Switches in large Power-Plants." Transactions of the American Institute of Electrical Engineers, vol. xxiii (1905), p. 199.

³ C. H. Merz and W. McLellan, "Power-Station Design." Journal of the Institution of Electrical Engineers, vol. 33, p. 696.

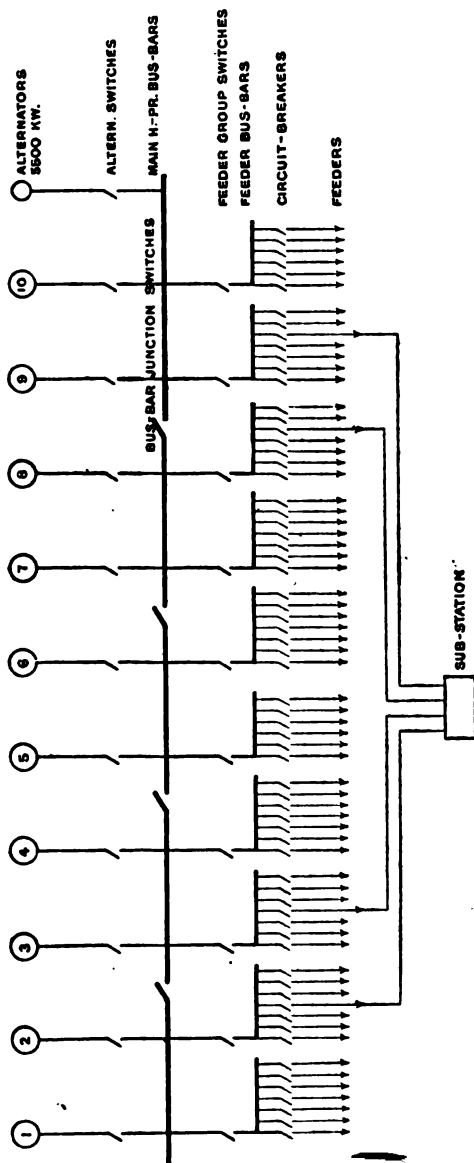
Fig. 7.



CIRCUITS WITH DUPLICATE MAIN BUS-BARS AND FEEDERS SUBDIVIDED INTO GROUPS, MAIN RAPID TRANSIT
GENERATING-STATION, NEW YORK.

number and size of machines, and the nature of the feeder network.

Fig. 8.



BUS-BAR ARRANGEMENT WITH FEEDERS SUBDIVIDED INTO GROUPS. CHELSEA GENERATING-STATION.

As a general rule, however, too much energy on any one part of the bars must be

made to cut out any section easily and quickly without discontinuing supply.

To allow of the group- and bus-junction switches being isolated for inspection or repairs, they are connected by means of ordinary knife-switches to the bus-bars. When these isolating-switches are open, slate or marble plates, fitting into grooves cut in the barriers of the bus-bar conduits, can be inserted between the contacts. This permits of work being undertaken on the isolated section free of danger from contact with the bars under pressure.

With a view to avoid possible risk when working on the bus-bars, each section is provided with special earthing-switches, securely clamped to the bars in the most convenient position for making the connections to the earth-bar. Provision should be made, throughout the switch-gear, for earthing all ironwork, transformer- and instrument-casings, for the protection of the personnel from the danger of accidental contact between these parts and any high-tension conductors. With the same object, one pole of the secondary of all instrument-transformers should be earthed, so that protection is afforded in case of contact between the primary and secondary windings.

In order to lay out these earth-connections in all high-tension compartments and on the operating-panels in a neat and systematic manner, about eight or ten bars of hard-drawn copper are run the whole length of the gear, near such apparatus as is to be connected with them. These bars are interconnected at their ends and, if very long, at intermediate places. They are carried to carefully grounded earth-plates, of which there should be at least two. The introduction of these earth-bars greatly simplifies the low-pressure wiring scheme between the high-tension compartments and the operating-panels, as a common return can be used for all instrument-transformers.

AUXILIARY HIGH-PRESSURE APPARATUS.

All auxiliary apparatus, such as protective devices¹ against high-pressure discharges, cable-charging gear and ground-detectors, is

¹ These devices serve to guard against breakdown of insulation due to abnormal rises of pressure, caused either by electric oscillations when a change of circuit conditions takes place, or by atmospheric disturbances. The nature of the sudden pressure-rises in high-tension networks, as well as the character of suitable protective devices, has of late years formed the subject of both theoretical and practical investigation. Messrs. Steinmetz, Percy H. Thomas, Blondel and others, have contributed much to elucidate these phenomena, but as yet a really satisfactory solution of the problem of effective protection remains to be found.

disposed, with regard to its isolation from neighbouring parts, according to the rules which hold good for the main gear. The high-pressure limiting devices, which are connected with the feeder-circuits, and usually take the form of a number of spark-gaps in series with either carbon or liquid resistances, are generally placed in the same compartments as the instrument-transformers (Figs. 6, Plate 1), or in separate cubicles of their own (Figs. 15, Plate 2).

Lightning-arresters, with their non-inductive resistances and choking-coils,¹ such as are employed in the case of overhead feeders, are best disposed in the top gallery near to the outgoing lines. Great care should be taken to lead the conductors up to this apparatus in as straight and direct a line as possible, in order to avoid the efficiency of the arresters being partially destroyed by self-induction in the connecting wires.

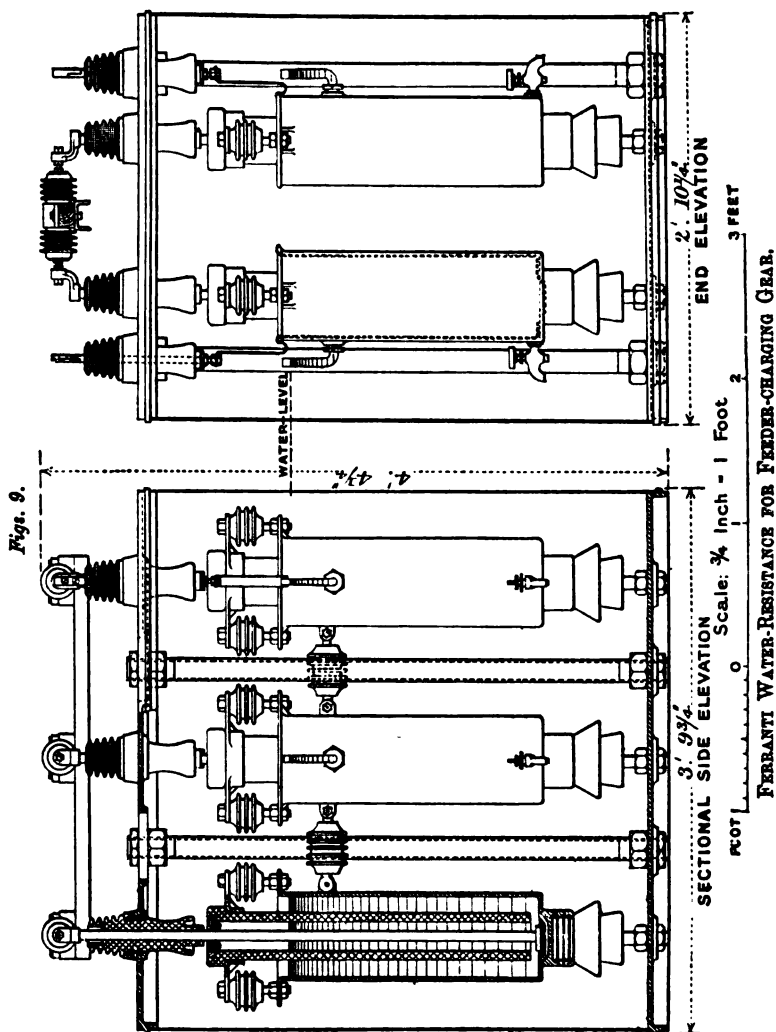
In order that the dischargers may be easily inspected and cleaned, without shutting down the feeders, they are connected with the latter by isolating-switches. When a feeder-compartment has to be isolated, this must be done not only on the bus-bar side but also on the sub-station side. Hence section-switches are inserted between the apparatus and the cable junction-boxes, and all danger of contact with the live cable is averted. For further protection, special earthing-switches are provided, which have to be closed before starting on repair-work. The three sets of isolating-switches—for the dischargers, for the feeders, and for earthing—may be united, and mounted on the same base-plate, each pole being on a separate plate, thus forming a triple switch per pole.

Provision is usually made for bringing the outgoing feeder-cables² up to normal pressure before they are switched on to the main bus-bars. This may be effected by charging the cables either with one of the main machines or with an auxiliary motor-generator; by employing the Ferranti liquid resistance; or by the application of the Partridge transformer system. In all cases the arrangements required on the high-tension side of the board are the same.

¹ Recently it has become the practice to connect each phase of the high-pressure system (bus-bars) permanently to earth by means of "water-jet resistances." According to all accounts from installations where this apparatus has been adopted, the results seem to be very satisfactory. The permanent loss due to leakage to earth is trifling when compared with the gain in safety.

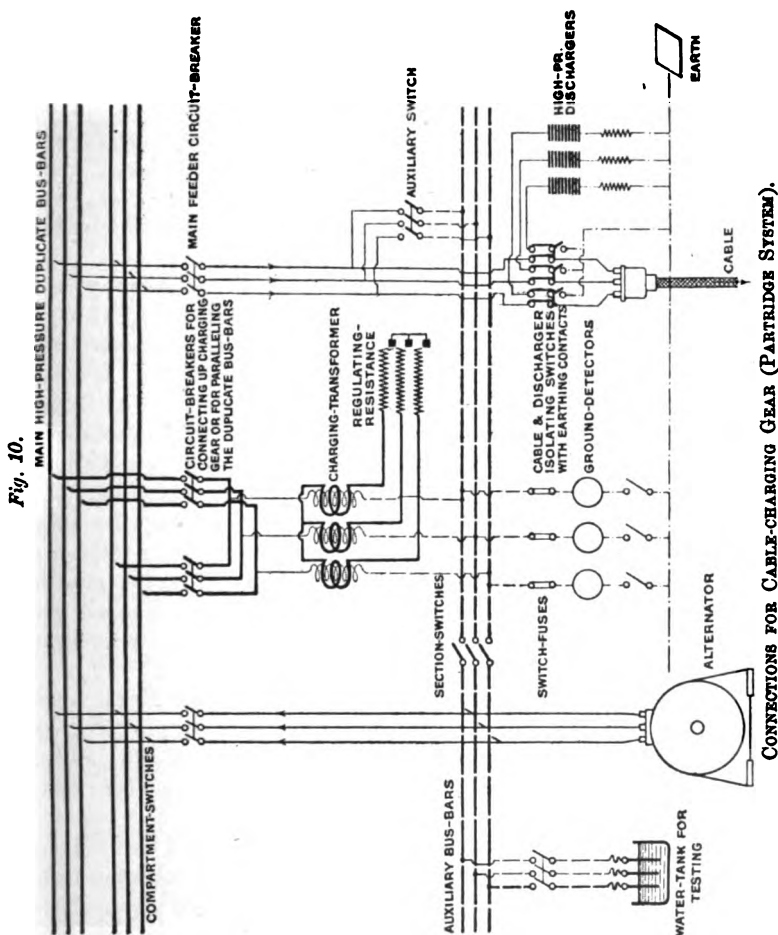
² With well-insulated cables and the employment of oil-break switches, the necessity of special devices for switching the cables in and out of circuit no longer exists in the same degree as formerly, when cable-insulation did not attain the perfection of the present day, and when air-break switches were in vogue.

The Ferranti resistance (*Figs. 9*) consists of two cast-iron vessels per phase, filled with acidulated water, and connected by two metal rods, the upper ends of which are connected together,



while the lower ends plunge into the vessels. The six rods are fixed to a common frame, which is raised or lowered by cords, operated by driving mechanism from the switchboard-platform. Each phase of the resistance should be placed in a separate masonry cubicle.

In the Partridge system (of which the connections are shown in Fig. 10), a transformer is used, large enough to furnish the charging-current for the longest feeder. One end of the primary of the transformer is connected, by means of two circuit-breakers, to either set of main bus-bars; the other end to an auxiliary set of bars,



which may be coupled to any of the feeders through a quick-break oil-switch. They, with the feeder in circuit, are then raised to the pressure of the main bus-bars, by decreasing the resistance in the secondary of the transformer, when the main circuit-breaker in the feeder-circuit is closed. In switching out,

the reverse process is adopted. The two circuit-breakers connecting the auxiliary with the main bars are provided with automatic overload release, and must be of the same size as the main feeder circuit-breakers on account of the power behind them. The auxiliary oil-switches may be of small capacity.

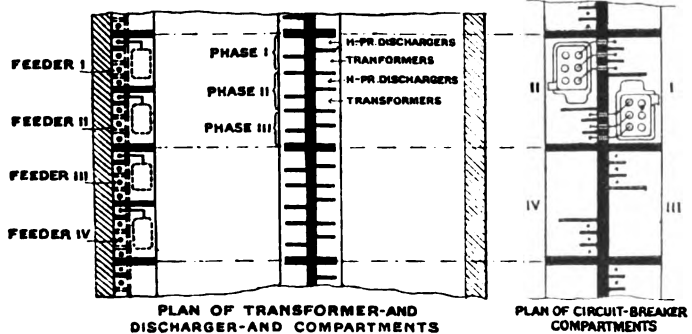
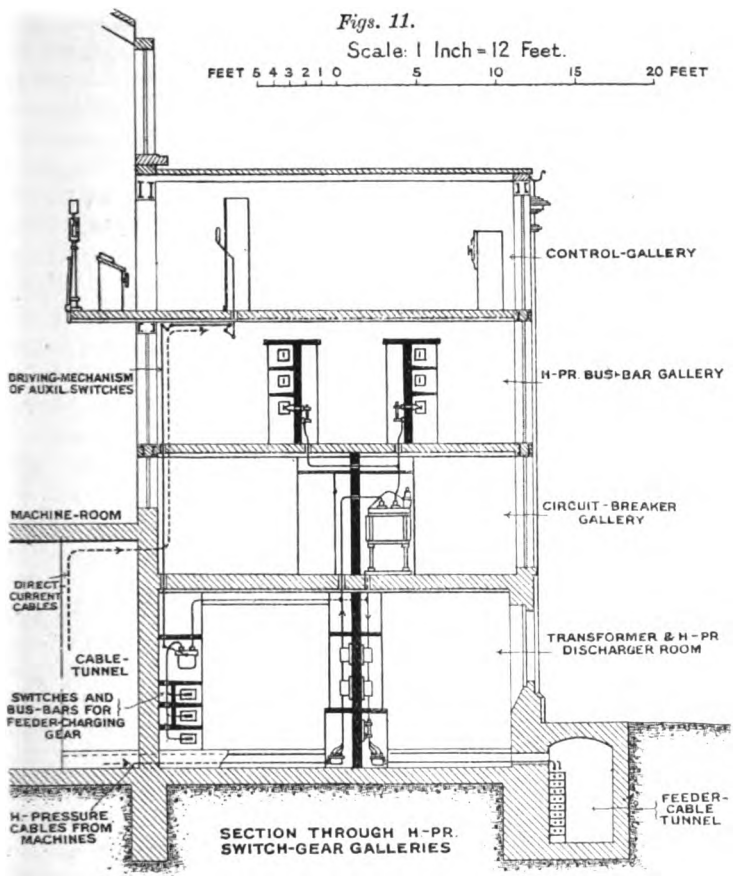
Of all devices for charging cables the Ferranti liquid resistance is certainly one of the simplest, and, on account of its mechanical design, the most reliable. It can be used for any kind or length of cable, without fear of resonance-effects such as may happen with the transformer system. Should the apparatus be kept in the circuit too long, the only result is that the water evaporates, whereas transformers may burn out and cause serious short-circuits.

An arrangement of cable-charging gear is shown in *Figs. 11*, where the auxiliary bus-bars, with the necessary non-automatic oil-switches, are disposed in a separate masonry structure.

In modern power-stations a permanent water-resistance is usually provided for loading up and testing the machines, and also for calibrating the instruments. The water-tank is built of concrete, lined with cement, and has the necessary pipe and valve-fittings for controlling the water-circulation. The electrodes, which are connected by flexible cables to fixed terminals, are suspended by cords from pulleys above the tank, and they can be lowered or raised by mechanical means according to the power to be absorbed. The size of such a tank for 2,000-kilowatt machines would be about 10 feet by 10 feet by 8 feet; and, as space is often an important factor, this capacity will be ample for far larger units, granted a sufficient water-supply for quick circulation. Control-panels with the necessary instruments are erected near these tanks to facilitate regulation of the energy absorbed.

Where cable-charging gear exists, the machines can be connected by means of the auxiliary bars to the testing-resistance (*Fig. 10*) instead of providing special cables for the purpose. To prevent interference with the charging of feeders the auxiliary bars must, of course, be suitably subdivided.

It is the usual practice to provide ground-detectors which indicate the insulation of the network, and thus permit of remedies being applied before complete failure of insulation has taken place. These detectors consist either of low-tension voltmeters and lamps connected through transformers to the high-tension bus-bars and to earth; or, of electrostatic voltmeters, branched directly off the high-pressure bars, or off condensers in circuit with them. A fourth voltmeter for measuring the pressure between the bars may be inserted between each leg of the system. The three or



ARRANGEMENT OF HIGH-PRESSURE SWITCH-GEAR SHOWING DISPOSAL OF CABLE-CHARGING APPARATUS.

four voltmeters, as the case may be, are joined up to the main high-tension bus-bars by means of oil-break switches which are interlocked with each other. All this apparatus is placed in a special masonry structure, separated from the rest of the high-tension apparatus, and within easy reach of the attendant (Figs. 6, Plate 1). In cases where feeder-charging gear is provided, the leakage-detectors may be arranged so that they can be connected to the feeder for testing purposes, while the feeder is being charged and before it is switched on to the main bus-bars, as shown for instance in *Fig. 10*.

The other device, which is often employed, consists of a three-phase star-wound transformer connected with the bus-bars through switch fuses, and with its neutral point earthed while the test is being made. The secondary of the transformer is wound in triangle, and a lamp, or voltmeter, is placed across each phase. Should one phase on the high-pressure system go to earth the lamp on that phase will be extinguished, thus indicating a fault.

LOW-PRESSURE CONTROL-GEAR.

In small plants all the low-tension instruments, meters, and apparatus may be placed on one board; but it is better in more important work to subdivide the low-tension gear. That portion of it necessary for the operation of the machines—starting up, paralleling, regulating, and shutting down—is placed either on a bench or on columns in front of the panels, and facing the engine-room (Figs. 15, Plate 2). The other portion, now consisting only of relays, the watt-hour meters, and the apparatus for the control of the exciter-circuits, is mounted on the low-tension or instrument board. When independent exciter-sets are used, a further subdivision may be made by placing the gear controlling these sets on a separate board, which could also contain the apparatus for the station-lighting and power-circuits. Further, by placing the synchronizing-instruments¹—the machine

¹ The adoption of electrically-operated circuit-breakers has made the use of automatic paralleling-devices possible, thus relieving the switchboard-attendant of a rather onerous duty. The condition of synchronism being equality of phase, periodicity, and pressure, successful paralleling depends on the moment for connecting the two circuits being properly timed. To render this manoeuvre automatic, suitable relays are provided, and when coincidence of the above-stated conditions is attained, these relays close the circuit of the driving-magnet, or motor, of the circuit-breaker, thus operating the latter. Several such synchronizing-devices have been brought out lately, and have been in successful operation in some of the large stations for the last 3 years.

and bus-bar voltmeters, the rotary synchronizer, and the synchronizing-lamps—together on a separate column, provided with a swivel headpiece, the instruments may at any time be turned to the most convenient angle at which they can be read from all parts of the operating-bench.

The separation described above greatly facilitates the duties of the engineer in charge of an important plant, as he is able to confine his attention while operating or, more especially, during breakdowns, to a fraction only of the whole switch-gear.

Separate columns (*Fig. 12* and *Figs. 14, Plate 2*) for each machine-unit are in many cases preferable to the bench-board, but where the latter is adopted its size should be restricted (by using edgewise instruments) and it should contain only the apparatus directly necessary for the control of the machines, the bus-junction switches, and the feeder group-switches. It would be mistaking the object of the whole design to do away with the instrument-board, and encumber the control-bench with such details as relays, energy-meters, power-factor indicators, and all the bars and connections appertaining to these. In the St. Denis power-station the low-pressure control-gear is divided into sections corresponding with the high-pressure units, and is mounted on a series of benches disposed directly above the high-pressure compartments, along the entire length of the switch-gear annex. Control from these benches would, however, be very difficult, owing to the great length they occupy, and therefore a "central control-board" is provided from which, under normal service conditions, operations are carried out. The "direct control-boards" merely form a reserve in case of accident. All machine circuit-breakers and bus-junction and group-switches, as well as the alternator field-regulators, are arranged for manual operation from the direct control panels and for electrical operation from the central board.¹

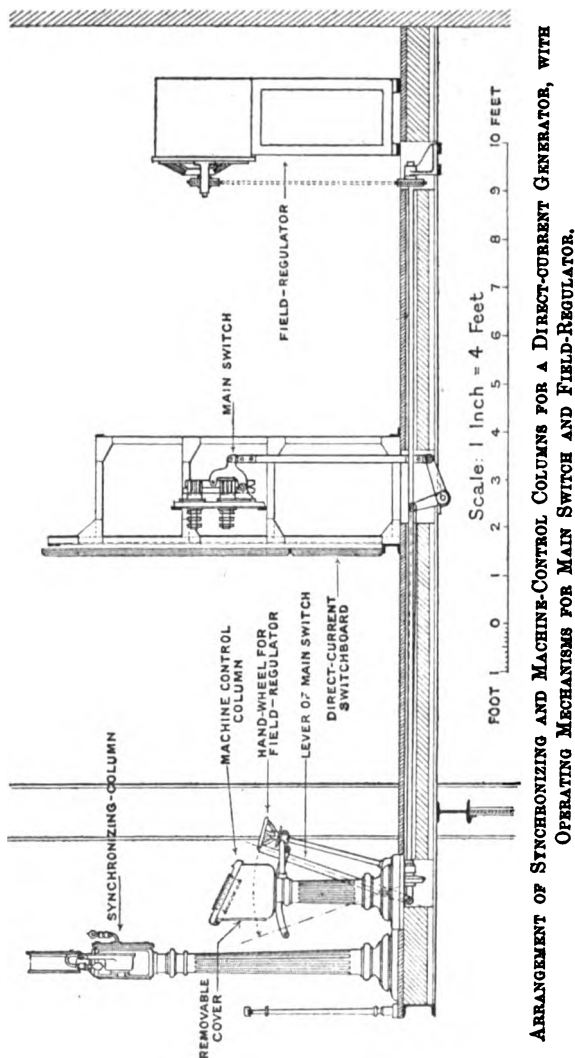
An important accessory to a modern switch-gear installation is the provision of signalling-apparatus, to enable orders given by the operator on the control-gallery to be transmitted to the man in charge of the machines. The simplest method would be to arrange a signal-bell and a few glow-lamps of different colours; for a power-station of some importance, however, a more elaborate system, similar to that used on ships, will be advisable.

When dealing with large generating-units, it has been found

¹ This combination of direct and central control with manual and electrical operation of the main high-pressure switches, is due to Dr. A. Della Riccia, Chief Engineer of the Société d'Électricité de Paris.

expedient to place near each machine an extra control-column, containing an ammeter, wattmeter, voltmeter, and the lever for the operation of an oil-break switch, so as to give the engineer attending

Fig. 12.



ARRANGEMENT OF SYNCHRONIZING AND MACHINE-CONTROL COLUMNS FOR A DIRECT-CURRENT GENERATOR, WITH OPERATING MECHANISMS FOR MAIN SWITCH AND FIELD-REGULATOR.

the machines complete control of the whole units—turbine or steam-engine, and generator. This arrangement is highly desirable for starting and testing, and in case of accidents. The current- and

potential-transformers for the instruments on the column, as well as the oil-break switch, are placed in masonry compartments in the basement. The switch, which is identical with the main circuit-breakers, minus the automatic devices, should in addition be provided with electrical release, so that it may be opened from the switchboard-platform. It would thus form a reserve, in case of emergency, to the main circuit-breaker. In fact, it may be advisable to cut the machines off the bus-bars first with these auxiliary switches, and only then open the circuit-breakers.

SWITCH-GEAR FOR AUXILIARY MACHINERY.

In the "Complete Unit" system all secondary machinery appertaining to one unit (such as the motors for ash-handling, air-pumps, circulating-pumps, economizers, fans, stokers, and exciters) is supplied from a transformer connected with the primary circuit of this unit. This system certainly has great merits for very high capacities, such as have been adopted during the last 3 or 4 years. The usual practice hitherto, however, has been to run this secondary machinery off auxiliary sets. Each motor should be joined to a different section of the main high-pressure bus-bars. The necessary switch-gear should be subdivided like the high-pressure gear, in order to avoid difficulties in case of a breakdown. It could at least be divided into two halves, with the machine-panels in the middle and the various feeder-panels arranged symmetrically on either side. Section-switches in the bus-bars would permit of either side of the board being used independently of the other. This entails practically no extra cost, and the gain is of great importance in case of repairs or extensions having to be carried out. Wherever possible, this sectioning should receive attention in designing alternating-current instrument-boards.¹

Various arrangements have been adopted for the auxiliary plant required for the excitation of the alternators. It is not unusual in stations of small output to provide an exciter for each alternator and to couple it either direct to the shaft of the main machine or drive it from the main machine by belting. In more important installations

¹ This symmetrical arrangement, as indicated for the auxiliary switch-gear in power-stations, might well be adopted in many cases for continuous-current traction and lighting-boards, instead of the system with the machines on one side and all the feeders on the other, with the impossibility of carrying out any work whatever on the board without either risk to the operator or shutting down completely.

the exciters are either direct-coupled or driven by independent engines. In many cases exciter-sets consisting of motor-generators are adopted in conjunction with a storage-battery. Other combinations, of course, are made to suit the special conditions of each individual plant.

Here again the switch-gear required must be designed with due regard to the condition that none of the main units ought ever to stand idle through a breakdown on any part of the excitation-machinery. A reserve supply of energy for excitation must be available, and the scheme of connections must be such that the field-windings of the alternators can, without loss of time, be switched off their normal supply-circuit on to the stand-by. In the case of direct-coupled exciters, these must be able to supply the excitation-energy required by the main units to which they are coupled, and to one or more of any other units whose exciters may have broken down. For this purpose a set of excitation bus-bars is provided, to which any exciter and any alternator field-circuit may be connected. When dealing with motor-generators in combination with a battery the latter usually serves as a stand-by, and arrangements should be made which will enable the excitation bus-bars to be switched on to the battery-bars.

The diagram of connections, Fig. 13, Plate 2, shows, for instance, a case where direct-coupled exciters are employed in conjunction with a battery. In the field-circuit of each alternator, a double-pole throw-over switch is inserted, permitting the machine to be coupled either with its own exciter or with the battery bus-bars.

Each field is of course provided with its own field-breaking switch and discharge resistance. The former is designed in such a manner that the field-windings are shunted by a non-inductive resistance before the field-circuit is opened. To enable the field-magnet windings to be completely isolated from the excitation bus-bars, for cleaning or for repairs, these switches should be of the two-pole type.

On account of the danger connected with the sudden opening of the highly inductive field-circuits, the field and throw-over switches are fitted with stops preventing manipulation until the catch is released. Safer than this device would be the interlocking of the field-switches with the regulators; no mistake in manipulating is then possible, as the field-switches can be opened and closed only when the regulators are in their zero position. They may also be fitted direct to the regulators, interlocked with these, and operated by their driving-mechanism. This would remove all heavy excitation-gear, such as bus-bars, throw-over switches, and connections

from the instrument-board, and would place them instead near the regulating- and starting-resistances, leaving free access to the many cables, terminals, instrument-resistances and shunts on the back of the board. Wherever possible the rheostats should be provided with mechanical in preference to electrical driving.

BUS-BARS AND CONNECTIONS.

Apart from the excitation bus-bars, which run the whole length of the alternator-panels, there are several other sets of low-pressure bars, mounted at the back of the operating-board. One of these sets is designed for synchronizing purposes, a second set serves for the operation of the circuit-breakers. When energy-meters and power-factor indicators are employed in the machine- and feeder-circuits, a number of current- and potential-transformers become necessary. Each set of instruments belonging to one circuit must, of course, possess its own series transformers; but a potential-transformer may be used in common for all the instruments (Fig. 13, Plate 2). To facilitate the connections between the potential-transformer and the instruments, a further set of low-pressure bars is mounted behind the instrument-board. Whenever two sets of main high-tension bus-bars are employed, one for lighting-circuits and the other for power-circuits, each series of main bars must be provided with its own pressure-transformers, and the low-tension bars must be duplicated. It may be noted that the potential-transformers employed for the instruments are also used for synchronizing.

The total number of high- and low-pressure and earthing bus-bars required for the switch-gear (Figs. 14, Plate 2) sums up as follows:—

(a) In the high-tension compartments:—

Two sets of main high-tension bus-bars, each set consisting of three bars.

One set of three auxiliary high-pressure bus-bars for the cable-charging gear.

Seven earthing-bars.

(b) Behind the low-tension instrument-panels:—

One set of two bars for the excitation of the alternators.

One set of two bars for the operating- and tripping-magnets (continuous-current) of the high-tension circuit-breakers

Two sets of two bars each for the instruments branched off the potential-transformers.

One set of bus-bars for lighting.

One earthing-bar.

All the low-tension bus-bars are of hard drawn copper of rectangular section and mounted on porcelain insulators. Only those for excitation carry heavy currents and are of comparatively large section ; but none of the low-tension bars should have a section smaller than 100 square millimetres, to ensure a thoroughly mechanical arrangement and allow the many small connections to be easily made.

The low-pressure connections between the various instruments should be laid out with great care, as a systematic wiring-scheme will render the arrangements more comprehensible, and will go far towards a good appearance of the back of the board. The small wires and cables are fixed, by means of insulating clamps, directly to the panels, thus leaving free access to the terminals of the instruments.

The back of the marble or slate panels should be painted with an insulating varnish before mounting the instruments or putting in the wiring, to prevent the otherwise inevitable stone-dust from soiling the various cables and apparatus.

The question whether all high- and low-pressure cabling belonging to the switch-gear should be insulated or not is one which has hardly yet received a definite answer. On the one hand, with non-insulated copper connections there is the danger to the personnel in case of accidental contact with live metal parts, and the danger of short-circuits. On the other hand, with insulated cable connections, especially when rubber is used, the risk of fire has to be taken into account. Insulating the connections, although more expensive, may, on the whole, be recommended. To obviate the risk of fire, all cables should be well separated from each other, and, whether for high or for low pressure, they should be protected with a double layer of asbestos braiding.¹ As the high-tension bus-bars are mounted in masonry compartments and can be isolated into sections for cleaning and repairs, no further protection is necessary. The low-tension bars, when they are of comparatively small section, should, however, be insulated with several layers of tape and then varnished. Bus-bars of large section, constituted usually of two, three, or more bars in parallel, should be left uninsulated on account of ventilation.

¹ A good method of procedure for the application of this fire-proof covering has been mentioned by Mr. H. W. Buck and adopted by the Niagara Falls Power Co. Asbestos tape is soaked in a solution of silicate of soda until thoroughly impregnated. It is then, while soft, wrapped spirally around the cable. This covering quickly hardens and forms a coating like stone over the braid of the cable. It is essential that the asbestos covering, to be thoroughly effective, be put on the cable after the latter has been put in place.

But in this case they must be mounted in such a position on the board that they will be safeguarded from accidental short-circuits. Throughout the whole gear the character of all cables, of whatever polarity or tension, should be easy of identification, preferably by colours.

A matter of great importance in the arrangement of the high-tension gear is that all cable-tunnels or trenches, and the spacing and size of the floor-girders, should be carefully considered when designing the buildings. In fact, it is advisable not to approve the plans for the buildings until the general arrangements for the switch-gear have been satisfactorily laid down.

With regard to the section and contact-surfaces of conductors, it is advisable not to determine these values altogether according to the usual rule of 500 amperes per square inch for sections and 100 amperes per square inch for contact-surfaces. It is essential that these current-carrying parts should be designed to ensure the necessary mechanical strength, and it will be found that the allowance to be made on this account will necessitate sections far larger than those required by what has been described above as the usual rule. Especially for high-pressure work, where the contact-pieces of the section-switches, circuit-breakers, etc., are fixed to large porcelain insulators and mounted on heavy base-plates, the proportions of the various parts must be in harmony with each other. It is inadmissible to design high-tension apparatus, relegated to masonry compartments, on the lines adopted for low-tension apparatus mounted on the operating-panels and unexposed to the comparatively rough treatment the high-tension gear has often to suffer. Not only here, but in all switch-gear design, the dimensions of the various parts should be apportioned in a liberal spirit. Neglect in this respect is frequently costly and always deplorable. To cite an example. The primary winding of the potential-transformers which feed the various instruments on the board is often a cause of trouble. The output of these transformers is very small, only about 50 to 250 watts, and their primaries are usually wound with a very fine wire of small mechanical strength, which after a certain period inevitably gives way; whereas a slight increase in the first cost would have ensured a more lasting apparatus.

Reliability in the smallest constructional details is of the greatest importance when dealing with such a multiplicity of apparatus as is required for the equipment of modern power-stations. This is partly obtained by devoting the most scrupulous attention to the mechanical design, and by not attempting to make economies at the cost of quality.

The Author wishes in conclusion to thank the "Ateliers de Constructions Électriques de Charleroi" for their kind permission to publish details relating to work which he has designed for them. Thanks are also due to Mr. M. B. Field, Assoc. M. Inst. C.E., for the drawings relating to the Ferranti circuit-breakers and cable-charging gear, and to Mr. H. O. Levis, Managing Director of the British Thomson-Houston Co., and Mr. S. B. Fortenbaugh, Electrical Engineer of the Underground Electric Railways Co. of London, through whose kind offices it has been possible to embody in the Paper the drawings relating to the Chelsea generating-station.

The Paper is accompanied by tracings and sunprints, from some of which the Figures in the text and Plates 1 and 2 have been prepared.

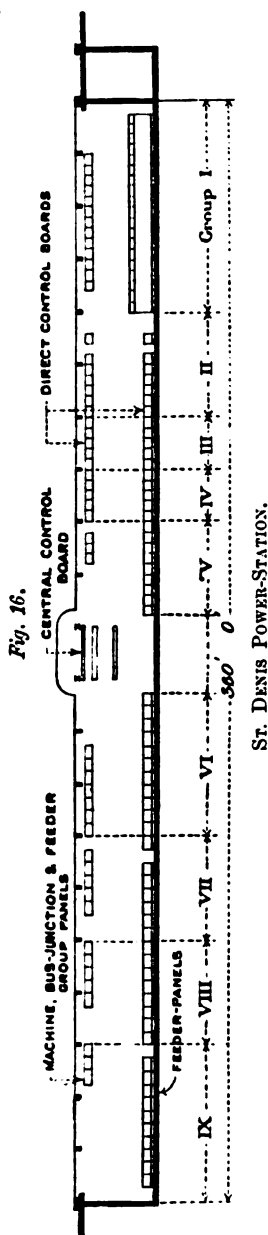
Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his The President. Paper, observed that it standardized a good deal of information which had been floating about, besides giving the valuable views of the Author himself.

The AUTHOR drew attention to *Fig. 16* (p. 36), which had been The Author. specially prepared to show the necessity in large power-stations of providing a reserve control—mechanical control from the benches, placed directly above the high-pressure compartments, electrical control from the central board. Obviously in large stations it was not possible to rely on the central board alone; there must be something to fall back upon in case of an accident to one portion of the gear. Supposing that, for some reason, such as a fire, the central board was put out of service, reliance could be placed on the control from the benches for continuing the supply.

Mr. LEONARD ANDREWS thought the Paper was somewhat difficult Mr. Andrews. to discuss, because, although it contained much useful information, engineers were now more or less in agreement with everything in it. If the Author had presented the Paper 4 or 5 years ago it might have led to a much more fighting debate than it was now likely to elicit. About that time he had the pleasure of seeing in America what he thought was the first remote-control board of the type shown, and on his return to England he discussed the question with several English engineers, and expressed the opinion that remote control, either electrical or mechanical, would become universal. At that period, however, engineers were accustomed to look upon the switchboard as a comparatively unimportant accessory to a generating-station, and it was considered that it would not be feasible to devote either the space or the capital required to installing a remote-control board in any but the very large power-stations then to be found chiefly in America. That was before the days of the fire at the Bristol electrical station; and he thought nearly all engineers now agreed that remote control was necessary, even for stations of a few thousand kilowatts output. There was one point in connection with the various arrangements of bus-bars that he did not remember to have seen brought out. In the arrangement shown in *Fig. 7* it appeared that there would be very considerable difficulty in getting away after a complete breakdown. The numerous generators were all shown capable of being connected

Mr. Andrews.



to two bus-bars only. Should a complete shut-down occur at a time of full load, in order to run the load up again it would be necessary to parallel all the generators before switching on the feeders, as it was obvious that if the feeders were left connected to the bus-bars no single generator could get away with the whole load of the feeders. Therefore it would appear to be necessary first of all to run up the generators, and then to switch on the feeders one by one afterwards. If it was necessary, as some engineers contended, to switch on all the feeders through a charging-device, it was obvious that the whole operation of getting away—first paralleling the generators, and then getting each feeder on—would take a very long time. That appeared to him to be an argument in favour of the arrangement shown in *Fig. 8*, in which the bus-bars were divided into four sections, or better still, the arrangement advocated by Mr. Merz, in which the bus-bar was divided so that the load on any section of it did not exceed the load that could be taken by any one generator. Should a breakdown occur on such a system when there were seven or eight generators running, each generator could be run up on its group of feeders and be paralleled with other groups of feeders and their respective generators at leisure. He had noticed, in connection with several switch-gears he had seen recently erected, that the oil-tanks were provided with taps for letting off the oil. It appeared to him that it was very desirable that such taps should be omitted, as being a source of danger. Evidently there was considerable risk that the tanks might be drained, either accidentally or maliciously; and if an oil-tank were left without any

oil in it a serious burn-out would follow. Another point of danger Mr. Andrews. in some designs of switch-gear was the isolating-switch. The arrangement shown in Fig. 1, Plate 1, seemed to be rather dangerous in that way, because apparently there was nothing to prevent an operator from opening accidentally that isolating-switch when the main circuit-breaker was closed, and if he did so it seemed likely that any arc formed would lick up on to the framework and possibly on to the bus-bars. Some simple arrangement should be provided so that it was impossible to open an isolating-switch when the main circuit-breaker was closed; or failing that, this switch should be put in such a position that, if an arc did result from opening it by accident, the arc could not lick on to any earthed parts or bus-bars, etc., of different polarity. The arrangement shown in Fig. 1 might be satisfactory if the isolating-switches were separated from other phases, as he presumed they would be, by vertical panels, and nothing placed over them. Another point he would like to hear discussed was the question whether it was desirable to use synchronizing bus-bars or to use separate synchronizers for every generator. It was a point he had heard discussed many times in private, but engineers still had different opinions about it. The synchronizing bus-bar appeared at first sight to be a simpler arrangement, but there was always the danger that alternators might be paralleled accidentally by two synchronizing switches being closed simultaneously, and that a breakdown might occur in that way. A synchronizer for each machine did not entail very much extra cost, and it seemed to be a better arrangement.

Mr. A. P. TROTTER asked why it was necessary to have so much Mr. Trotter. complication in these large switchboards. It had been assumed that they were necessary for large stations, but there seemed to be a big jump from a small station to a large station. The prototype of all high-pressure stations, Deptford, which he knew fairly well, and which had been running for 13 years, would serve to illustrate his point. He did not know what the rated output was, but he did not suppose that, even multiplying it by four, would give 30,000 kilowatts single-phase. If it were turned into three-phase the switch-handles would not be correspondingly multiplied, and although the switchboard certainly would be a good deal larger, there would still be nothing like the complication that was considered necessary in some stations. It was easy to press a button and allow the relay to do the rest, but was that a trustworthy form of control? It was an elementary axiom with most engineers, especially electrical engineers, to do nothing electrically that could be done mechanically. Remote control, of course, was an important matter for safety as well as continuity of supply but it did appear that some control could be

Mr. Trotter. done by levers and rods, and it might be well to turn over the whole thing, say, to Messrs. Saxby and Farmer, or to Messrs. Sykes, to see what they would make of it. He had seen plain rod-and-lever work in several small stations. On p. 29 the Author said, "The switch, which is identical with the main circuit-breakers, minus the automatic devices, should in addition be provided with electrical release, so that it may be opened from the switchboard-platform." Why should there not be a trigger which could be tripped by pulling a wire, run like an old-fashioned bell-wire? He did not see why it should be done electrically; and a good many other things, he thought, could be done mechanically with greater certainty than was afforded by the immensely complicated gear now used. In all large engineering devices complications must necessarily come in. A 3,000-HP. steam-engine was not a 30-HP. engine on a larger scale. As regarded safety, he noticed that, in the description of the floor of the gallery, nothing was said about glass flooring; he had seen some very good examples of it lately, and it seemed to conduce considerably to safety—although a man should not be asked to do anything on a glass floor which he ought not to do on an iron floor. With regard to the use of oil, ever since he saw the Bristol station after the fire, and heard the probable cause of that fire, he had been rather suspicious of oil in switches, fuses, and transformers. The danger had hardly been foreseen; and at Bristol it had arisen from a quart or two of oil. The flooding of the platform with only $\frac{1}{2}$ gallon of oil fired the whole place, and wrecked the station. It might be urged that modern oil-switches were rendered safe by the number of precautions that were taken. He found that numerous precautions were mentioned in the Paper as having been taken for the safety of a large switch; first of all there was a powerful spring; secondly, insulating partitions divided the switch into three compartments; thirdly, there were lowering arrangements, since it was important to be readily able to inspect the contacts; fourthly, the tanks were made of sheet metal lined with wood; fifthly, precautions were taken to prevent contact between phases; sixthly, precautions to prevent contact between the main contacts; and seventhly, precautions so that, should the contacts break, arcking to the flame was further protected by a sheeting of micranite. There were at least seven, and might be more. If all those precautions were needed, it showed that the design of a safe oil-switch was rather a formidable matter. He had heard of a case where arcking took place on to the oil-container, which was burnt through, and burning oil came out. Since the fire at Bristol he had urged that provision should be made for coping with such an accident, and one

very simple thing, which could almost always be done, was to put Mr. Trotter. enough gravel or ballast, which was perhaps better than sand, underneath the oil-box, to absorb the oil and put it out if it was burning. With a transformer that could not so easily be done. In that he must differ from Mr. Andrews, because he thought that in case of fire, provision should be made to let the oil run out of the building. The drain should have cast-iron gratings through which the burning oil could run, the cold cast iron probably putting the fire out. That suggestion would be extremely simple to carry out, and he threw it out as a preventive of the bad accidents that had happened, and might happen again, having regard to the complication of the switches and the precautions already found necessary to render them safe. Another matter related to the detection of faults upon the line. In a foot-note to p. 21 water-jet resistances were mentioned. Water-jet resistances were used in connection with lightning-arresters, and he believed they were used in the North Wales system. Such resistances sometimes took about 1 kilowatt each, but they were meant, he thought, to be used as a rule only during a thunderstorm. Further on in the Paper the question of putting transformers to earth was mentioned. If the American principle was adopted of earthing the middle point of the star winding, anything like a fault was likely to develop into a short-circuit, and there would be a shut-down. He understood that cables for such work were cheaper than cables where no earthing was to be allowed. The voltage might be anything up to the voltage across the phases. But if for any reason it was not desired to earth the middle point of the star winding, the most simple and trustworthy fault-detector appeared to be three electrostatic voltmeters, one on each phase to earth. An objection to that was that engineers did not want to bring the whole pressure on to their switchboard; but in two or three stations he knew of, voltmeters were put high up on the board, and the pressure-wires came through high overhead. Of course, it would be better if lower pressure could be brought upon the board without those risks. The pressure could be taken off condensers in series, tapping the pressure required for the voltmeters off the condenser, and that seemed a very good plan; but when low-pressure voltmeters were supplied through transformers, the primaries of the transformers had to be put to earth, and the question arose whether that earthing through the high resistance of the transformers would swamp any incipient leak upon the cables. That was a matter which those who were more conversant with the details than himself could settle; but it appeared to him that a small fault might occur, hardly visible because of the connection with earth already from each phase

Mr. Trotter. through the transformers, and therefore the other system appeared to be better. In the other device of the three-phase star-wound transformer he noticed that the neutral point was earthed only while the test was being made. It was of considerable importance to be able to watch the insulation at the mains and to look after them, if they were going down, before a fault appeared.

Mr. Jenkin. Mr. BERNARD M. JENKIN, referring to Mr. Trotter's comment upon the danger of oil, observed that, judging from an accident which he had seen quite recently, caused by an explosion of oil, he did not think Mr. Trotter's suggestion would meet the case. Apparently what happened in an explosion with an oil-switch, or small transformer with oil round it, was that the arc set up sufficient pressure to blow the oil out of either box or transformer in the form of a spray, which was at once ignited by the arc and exploded: it did not run out of the box. So that the cooling-effect of gravel in a tray for catching the oil beneath would probably not come into play at all. It was difficult to see how to deal with the oil, and Mr. Trotter's suggested means of carrying it out of buildings seemed to Mr. Jenkin to be likely to render high-tension boards even more difficult to build than they were now. It was exceedingly difficult to take all necessary precautions and yet keep the apparatus within reasonable dimensions, and the reason why high-tension boards had grown to such a size was the necessity of taking greater precautions. When the boards were small, as the Ferranti boards originally were, they could be got into a small space; but accidents had occurred, and it had been necessary to adopt something to separate each switch, instrument, transformer, etc., from the others, in order to prevent the spread of such accidents. Even in the boards shown he noticed that there were apparently no doors placed on the cells, and that was perhaps an additional precaution that ought to be taken. It often became necessary, when there was a breakdown, to remedy it while the rest of the board was in use. Men had to be allowed to go along the galleries carrying tools and wires, and if the partitions simply projected with open sides the men would infallibly get their tools and wires into contact with high-tension circuits. Even when doors were provided, they left the doors open and touched the high-tension circuits. Only the other day, a contractor's boy went along a gallery, and, in spite of all the iron doors to the cells, he touched a high-tension circuit with a wire. He was fortunately standing on a glass floor and only got his fingers burned—in fact, he was at work again the next day; but such good luck could not be expected every time. Therefore Mr. Jenkin thought boards without doors would be extremely dangerous to

repair on that account. If any of the oil-switches or any of the instruments were to explode, the fire would spread and start arcs on some of the neighbouring circuits because they had not been closed in that way. He noticed in some of the illustrations that great care was taken to separate each phase of one circuit, and yet all the phases were brought together again at the switch. In the bottom right-hand corner of *Figs. 11* there was a switch with all three phases coming together, but the three phases were separated by partitions at the back. If the phases were next to each other without any separating partitions at the dangerous point, which was at the switch, he could not see that very much was gained by separating them on the other side of the wall. He thought the idea of separating the different conductors in the same circuit was perhaps carried too far, and it certainly increased the size of the board very much. He had heard of a good deal of difficulty with the electric control of switches, and he would like to hear what the Author had to say about it. The time taken to operate the switches electrically introduced a difficulty, as sometimes the machines did not stay in synchronism long enough to enable the electrical operation of the switch to take place; that was, machines had begun to get out of step before the switch closed. If the switch was worked mechanically it could be made to close at the exact instant the operator wished.

Mr. J. E. WOODBRIDGE, of Rugby, remarked that the Paper showed several highly advantageous principles of high-tension switch-gear, principles that had been followed in English switch-gear even to a greater extent than in some of the Author's examples. The Author developed his principles to their logical results, one result being, in the case of a station of upwards of 20,000 kilowatts, switch-gear occupying four stories, about 100 feet in length and 20 or 25 feet in width—probably a greater volume per kilowatt than was required for the corresponding turbo-generators. The cost of gear developed along these lines for high-tension plant, together with sub-stations for the conversion of the energy into continuous current and its distribution, amounted to about £4 to £6 per kilowatt, depending on the number of units; and for some English stations the cost was even higher. He knew of one system of moderately large size for which the figure was nearly £10 per kilowatt, and probably there were others like it, judging from the appearance of the stations. That compared rather unfavourably with the cost of electrical machines, and on the usual English lighting load-factor it threatened an additional 0.1d. per unit for capital charges on switch-gear, especially if the depreciation-charges on the gear

Mr. Wood-
bridge.

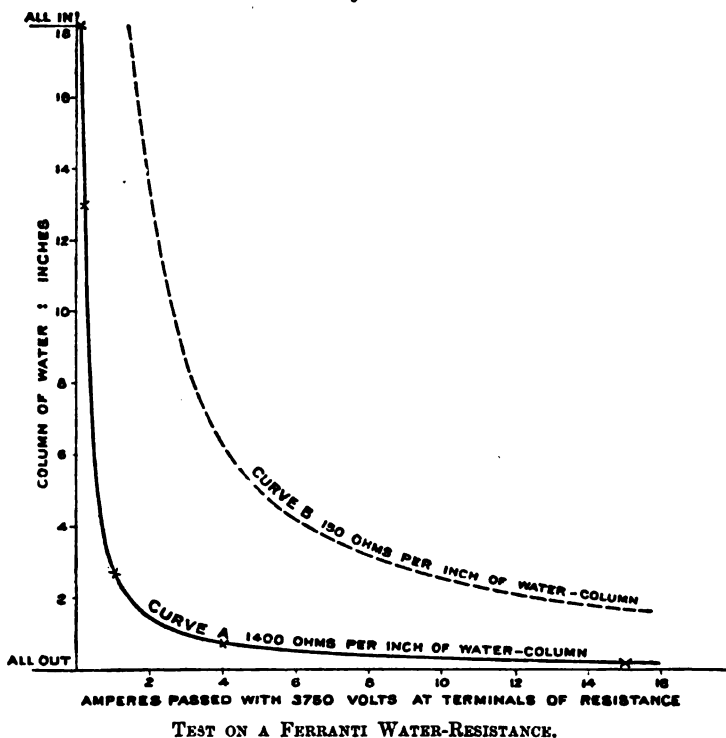
Mr. Wood-bridge. were made high enough to cover the rapid development which called for replacement of switch-gear before long. But that was not all. The complication involved in the duplicate bus-bars and elaborate relay-systems was a real hindrance in time of emergency, which was the only time when a good deal of the switch-gear was ever used. He had heard much argument as to whether part of a system was dead or was not dead in a station laid out on those complicated lines. He had also seen an operator in a time of emergency run along the whole line of panels and open every switch he could get hold of. When the gear was scattered in four galleries and in many compartments he might not see what the trouble was ; every needle was hard over, and all the machines were groaning, and in his desire to remove the trouble he removed the supply at the same time. Mr. Andrew Carnegie had said that he acted on the maxim "Put all your eggs in one basket, and then watch that basket." Mr. Woodbridge believed in putting all the power in one bus-bar and all the oil in one oil-switch per circuit ; putting all the instruments on one current-transformer, and one potential-transformer if possible ; putting in as few section-switches as possible and consolidating the remaining gear into as small a space as practicable, due regard being paid to clearance and so forth ; and getting all gear within easy access of the operators—and if possible in a small station within their sight—proper precaution being taken, by screens, etc., to avoid too easy access. The choice of high-tension switch-gear was largely a matter of expediency, and it was easier to get too much than too little. Consequently, the question was whether principles should be followed to their very end or whether a compromise should be effected by the exercise of a certain amount of common sense. He had heard it claimed for the Thury high-tension series transmission of power by continuous current, that one of its strongest points was its extreme simplicity. There was no switchboard, because it was impossible to make switch-gear that would do for continuous current all the things that could be done for alternating current. He sometimes wished it was impossible with alternating current.

Mr. Roberts. Mr. R. C. ROBERTS pointed out that in saying (p. 2) that any metallic framework, being liable to cause dead short-circuits in case of breakage of insulators, had been dispensed with altogether in more recent designs, the Author made rather a sweeping statement, because there seemed to be some advantage in having metallic framework. Explosions of oil, from switches and transformers, were very violent, and a stout steel framework added to the mechanical strength and supported the stone cell-work. Apart

from mechanical considerations, there was also an electrical one. Mr. Roberts. He had heard that a high-tension leak could get on to stone-work and masonry, and in one case he believed a very bad shock had been obtained from a wall 20 to 30 yards away from any switch-gear, simply owing to a leak. If all high-tension gear were included in a cage-work of earthed metal it would act as a safety device against that liability. He had not seen the occurrence himself, but it seemed rather important, and Mr. Trotter might like to know of it. With regard to what Mr. Andrews had said about high-tension synchronizing bars and the liability of synchronizing on to one set of bus-bars when the instruments were connected on to another, that contingency could be dealt with by an interlock, mechanical or electrical. The mechanical form was of course preferable and had been found to act efficiently. High-tension circuit-breakers had to open under the most unfavourable conditions, and those conditions were controlled largely by the capacity of the plant at the generating-station; it was not the capacity of the circuit controlled, it was the energy that could be pumped into short-circuits which practically affected the circuit-breaker. He had had experience with both static and transformer voltmeters, used as earth-detectors, and had found that the static were more efficient than the others; in cases where there was a control-panel in front of the high-tension cells it was possible to have a window to look through, so that the static voltmeters were not brought near any low-tension wiring. The Ferranti water-resistances, of which he had had some experience, worked very well, but the adjustment near the bottom was very delicate, and involved some risk of causing a short-circuit. *Fig. 17* showed the current passed by the Ferranti water-resistance for different positions of the rods, and with a constant terminal voltage equivalent to the voltage per phase of the system on which it was used. The curve was hyperbolic, corresponding to a constant sectional area of water-column. By altering the conductivity of the water used, a wide range of curves was available, and it might be found feasible to improve the shape of the curve for practical working by altering the proportions of the porcelain pots. The Author raised the difficult question whether high- and low-pressure cabling should be insulated or not. There were distinct advantages in having bare rods, but rigidity was essential, so that it should be impossible for them to come together in case of a short-circuit. The forces attracting the rods together in the case of a short-circuit were much greater than was generally realized. In connection with the Author's insistence upon the necessity of designing current-carrying parts to secure adequate mechanical

Mr. Roberts. strength, Mr. Roberts would point out that solder should be avoided as much as possible. The use of solder was a dangerous thing in switch-gear, for in case of short-circuits or other emergencies, the solder was apt to run out and get on to other gear and connections,

Fig. 17.



thus making things much worse; such a failure in the relay-connections absolutely stopped the circuit-breakers from working automatically.

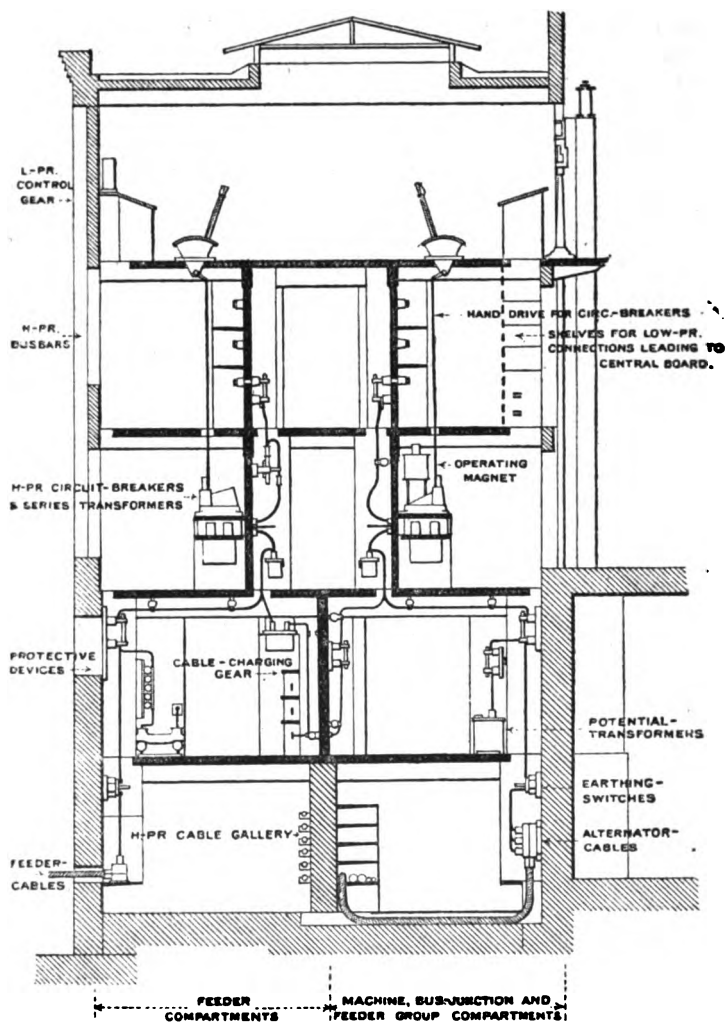
Mr. Edgecumbe. Mr. K. W. E. EDGCUMBE asked whether the Author had had any experience of using condensers in series with electrostatic voltmeters as leakage-indicators. His own experience was that that was not very satisfactory. As a rule, the capacity of the condensers, being very small, was rather dependent on atmospheric conditions, and so forth, and threw the indicators out. Reference had been made in the discussion to using separate synchronizers for each machine, but he took it that Mr. Andrews only meant separate transformers for each

generator. It would not be necessary to duplicate the synchronizers Mr. Edgecumbe. themselves and it was certainly a great simplification to use several transformers instead of having to complicate the high-tension gear.

The AUTHOR, in reply, with reference to the question of The Author. separate synchronizing transformers, raised by Mr. Andrews, pointed out that in the system of *Fig. 8*, as applied to the St. Denis station, each section of the bus-bars had its own synchronizing transformer, so that the machine connected with the group could be synchronized directly with the group, no mistake being possible. There were no synchronizing-bars in that case. Oil-taps had been disused simply because of the leakage; instead of oil-taps conical screws were used, which when properly screwed up practically never became loose. As to Mr. Trotter's remarks advocating a mechanical drive in large switch-gear, an example of mechanical control, at the St. Denis station, was shown in *Fig. 18*; and he would also remind Mr. Trotter of what was said in the Paper as to the advisability of having mechanical control whenever possible. From *Fig. 16* it was easily seen that, for switch-gear which occupied a length of about 360 feet in a station of 70,000 kilowatts with about seventy feeders, it was necessary to provide some reserve control, which in this case was mechanical. Another example of mechanical control was shown in *Figs. 6, Plate 1*, as applied in the Port Dundas lighting-station. Mr. Trotter had also proposed to control mechanically, instead of electrically, the switches placed near the control-columns. In the St. Denis station each of the twelve machines had its own column, and it would be quite impracticable to connect the switches, by means of steel wire or cable and the necessary guide-pulleys, etc., with the central board, on account of the distance. In the Port Dundas station the floor in front of the operating-panels was of glass, but he did not think glass flooring was at all necessary. It might have been necessary in earlier days when switchboards had not the same factor of safety as they had now. As to the amount of oil in switches, he would like to draw attention to the switches of the General Electric Company, shown in *Fig. 15, Plate 2*; the quantity of oil was very small and there was the great advantage of having the oil-chambers separate; each pole had two breaks, and each break was in a different chamber or metal tank. Smaller switches were also built into masonry compartments, and at the bottom of the masonry compartment there was a kind of trough to take up the oil if it leaked out or in the event of an accident. If that trough were filled with sand, as proposed by Mr. Trotter, it would obviate largely the risk of fire. As to the electrostatic voltmeters and

The Author. their position with regard to the switchboard, in the Port Dundas station, for instance, they were mounted in special masonry com-

Fig. 18.



ST. DENIS POWER-STATION.

partments, and being on the same level as the operating-board, were of course easily accessible. With regard to Mr. Jenkin's remarks about putting doors in front of the cells, such doors were shown

in Figs. 6, Plate 1, and were of perforated sheet metal. Personally, The Author. he did not think metal doors ought to be used: all metal work was more or less dangerous, and only served to spread the arc where arcking occurred. A better plan would be to close off the high-tension room altogether, and as, in the case of repairs or inspection, each unit could be cut off separately from the bus-bars, he did not think there was any danger to workmen occupied in one of the isolated cells. As the gear was built in three or four stories, a certain amount of precaution has to be taken to ensure the section-switches being left open. To minimize the risk of danger, each of the main circuits was provided with earthing-switches. With reference to the three phases coming together in one switch, Figs. 15, Plate 2, showed the switches in the Lot's Road power-station, where the phases were quite separate. There were brick barriers to prevent one phase from coming in contact with the other. It would also be seen from this figure that the General Electric Company's switch presented an ideal coupling system; the cables entered from the bottom and there was absolutely no possibility of the cables touching, or of arcking between them, as each cable was separated from the other by a stone barrier. Tests of the time taken to close one of the electrically-operated switches had shown that the time-element need not be taken into account, being less than 1 second for switches of a normal capacity of 1,000 kilowatts and about 1.5 to 1.75 second for switches of 5,000 kilowatts capacity; and it was hardly possible to improve upon that, even with mechanical control. Mechanical operation would certainly take more time than electrical operation in any of the large switches, as he knew from experience. In several modern power-stations an automatic synchronizer was introduced, so that the operator had practically no trouble whatever in synchronizing. He had never heard of a case of leakage on to masonry, and he thought if the insulators were sufficiently large and well corrugated, with long surfaces, there was no danger. It was essential that switches should be designed for the power behind them. Whenever a client inquired the cost of a switch, the first question asked concerned the amount of energy behind the switch. In large stations that energy was, under ordinary circumstances, about 30,000 HP., and it might be larger. If two or three of the groups were coupled together there might be about 60,000 HP. behind one of the switches in case of a short-circuit, and that was why such elaborate precautions had to be taken in high-pressure gear. With reference to the complication in large-capacity switch-gear, objected to by Mr. Trotter, if Fig. 18 was carefully examined, and one unit only

The Author. taken, it would be found that there was a minimum of apparatus ; there was the cable-box belonging to the alternator, the synchronizing-transformer with its fuses, the earthing-switch, two series transformers, each in a different phase for the relays, and a second set of two series transformers for the watt-hour meters, the section-switches, and bus-bars. He did not think it possible to have switch-gear simpler than that. There was no duplication of apparatus except the two sets of series transformers, and that was due to one maker having furnished the watt-hour meters and another maker the relay and other meters. It was similar with the feeder-circuit.

Correspondence.

Mr. Clothier. Mr. H. W. CLOTHIER remarked that about 5 years ago he endeavoured to classify several types of switch-gear then known,¹ and at that time it was felt, owing to the rapid advances in capacities to be dealt with and in the higher voltages used, that a change in the system was imminent. Also it was felt that some steps were necessary in order to standardize the demand for switch-gear work. The Paper was consequently of no common interest to him, being a modern treatise of greater value upon the same subject. On making a cursory comparison it was noticeable that the developments in the past had not had any tendency towards simplicity: on the contrary, for large capacities the tendency at present in England appeared to follow the practice set many years ago in America; and the apparatus once known as a switchboard was something like a warehouse containing separate floors for the storage of different commodities, with a show-room for the display of delicate instruments and appliances. The elements which constituted a power-station switchboard had multiplied, each additional element appearing to introduce a train of others, until a drawing or a diagram of connections even for a few panels, as indicated by the Paper, became almost too complex to be understood without the most careful consideration. It was time now for designers to look back upon some of the simpler designs in the past, and for a strong hand to strike out the superfluous parts and details. Obviously many improvements must be retained ; but he believed the switch-gear of the future was

¹ "The Construction of High-Tension Central Station Switch-Gears, with a Comparison of British and Foreign Methods." *Journal of the Institution of Electrical Engineers*, vol. xxxi (1902), p. 1247.

destined to have features which would enable it to supersede its Mr. Clothier. predecessors in safety and simplicity, and consequently effect a saving in capital, working-, and maintenance-costs; for he could not think that the apparatus described in the Paper represented finality in switch-gear construction. The detailed construction of switches was of interest, although it was, perhaps, difficult to see where any striking improvements had been made upon the switches published in American papers about 5 or 6 years ago. The double solenoid control shown in Figs. 4, Plate 1, was extremely ingenious, but it was doubtful whether the extra solenoid compensated for the complication which it introduced. Certainly a long break was obtained with comparatively light moving parts, but was the length of break necessary under oil for a 3,000-kilowatt switch at 10,000 volts? Presuming there was a clearance at the break of about 9 inches, as it was a double break there was an actual break of 18 inches through oil; but this was not at all consistent with the clearance at the side of the contacts to earth, which to scale was not more than 2 inches, or the surface insulation above the contact, which scaled only about $2\frac{1}{2}$ inches. Ample clearance was an important factor in switch-design, and he believed in being well on the safe side; but he suggested that if these switches were made without the complicated double solenoid and with a shorter travel, the break would be more consistent with the clearances on the other parts of the switch. Also, retaining the same depth of tank, the length gained could be used to advantage in increasing the head of the oil above the breaking-points, which would appear to be of more service than an extra long break. Mr. Ferranti had been one of the first engineers to utilize the high insulating properties of oil, and it seemed a trifle incongruous that this experience should be used with such disregard for proportions in an apparatus which was excellent in other respects and well deserved its place in a treatise upon modern switch-gear. The maintenance of an arc through oil, despite the fact that bad oils were being used, was of very rare occurrence indeed. He had never seen an oil-switch fail from this cause. The only failures in oil-switches which had occurred to his knowledge had been due either to the absence of oil in the switch, or to an explosive effect bursting the vessels containing the oil, or else to the maintenance of an arc across parts outside the oil; and he thought that some account of the Author's experience in this direction would add to the value of the Paper. The foot-notes recalled many past works which had had a strong controlling influence over switch-gear design, but he could not agree with the remarks relating to discriminating devices, and he did not think that the maxim

Mr. Clothier. extracted from Mr. Andrews's important work was at all self-evident or conclusive. It was comprehensive only within certain limits, because there were many branches where current might feed a bus-bar at one time, and through the same branches current might be led away from the bus-bar as the load was transferred from one part of the power-transmission system to another, such as was the case with inter-connectors between stations and ring mains. Moreover, over-load-devices for generators were a very old and simple form of protection, but, he suggested, none the less effectual or reliable, provided they were set high enough. He agreed with the statement that cable-charging gears should not have the same share of attention as in the past, and he was somewhat surprised to see such prominence given to this subject in the Paper. He believed that he had originally proposed the use of water-resistances for cable-charging at a time when Mr. Ferranti's ideas on the subject took another course, and he ventured to suggest that it was due to some investigations which he had made for Mr. Ferranti that the apparatus described by the Author had found its way into practice. Even at the time the idea was promoted, it was a very debatable point whether cable-charging apparatus would be installed upon some of the larger power-schemes then under consideration; but in one case at least the decision in favour of the cable-charging gear had been encouraged because a simplification in the arrangement of the feeder-panels was rendered possible, and some extensive switch-gear had been made with no quick-break switches, but, instead, provision for breaking as well as charging a circuit either loaded or unloaded through the water-resistances. This feature, however, in favour of the use of charging-apparatus, now disappeared, because the present practice demanded circuit-breakers on the feeders, whereas at one time fuses were employed; and so it was to be expected that the switch-gear of the future would not be encumbered by cable-charging apparatus and connections thereto, with the attendant train of accessories. Great attention should be given to reducing absolutely to a minimum the duplication of parts. For example, the addition of oil-break switches near a steam-turbine was likely to be more a source of danger than of convenience: it was desirable to keep all switch-apparatus under control from the main station operating-platform, and the extra control-column containing instruments for the use of the engineer attending the machine did not appear to him to have the merits which warranted an acceptance of the Author's suggestion. All designers would agree with the Author's concluding remarks concerning the reliability of the smallest constructional details when dealing with a multiplicity of apparatus; but Mr. Clothier

would add that equal importance must be attached to the reduction of apparatus in order to ensure economy in the long run, and hence to advance the electrical industry as a whole. Mr. Clothier.

Mr. G. W. PARTRIDGE considered that the arrangement of switch-gear was becoming more complicated every day, and he would strongly urge designers to pause ere they installed further complications and apparatus. In his opinion, the control of large generators should be left entirely in the hands of the switch-man in charge, who should switch them in and out when he pleased. He was much averse to the use of reverse or maximum-current circuit-breakers on generators. In the event of there being anything wrong on the system, or of a sudden overload coming on, this might cause the generators to fall slightly out of step, causing an interchange of current between them, in which case the automatic arrangements nearly always acted and made matters worse than they were before, through the machines being taken out of circuit when they were most wanted. When inspecting the switch-gear at the St. Denis station in Paris, he had noticed that the reverse-current circuit-breakers on the generators were set to go only when the voltage had fallen more than 50 per cent. of the normal; but even this arrangement was not as safe as the hand-control of large machines. He had seen a sudden short-circuit throw large alternators out of balance when they were running on a rapidly rising load; had any of these machines been switched out it would have meant practically shutting down the whole station, owing to the generating-sets being of large capacity and few in number. In this particular instance, the alternators were gradually brought in step again and the supply resumed. The same objection applied to the automatic paralleling device, which might work satisfactorily until something went wrong; and he much doubted if this device would operate if it were necessary to synchronize machines at a low voltage. From his experience it was necessary at certain times, in cases of emergency, to put machines into parallel at low voltages, and sometimes slightly out of phase. He therefore thought that simplicity of design should be the chief aim and object of switch-gear. He had often noticed in large modern stations that half the automatic apparatus was either tied up with string or wedged up with pieces of wood to prevent it from acting when it was not wanted. He had lately been shown over a large modern station, and the engineer in charge, in going over an amazing amount of switch-gear and interlocking arrangements, showed him one or two devices by which, he claimed, one man could, if he desired, shut down every machine in the station by manipu-

Mr. Partridge. lating one switch. Mr. Partridge would have thought it better practice to make it as difficult to shut down a station as possible, and not to have such complications in use. The high-tension oil-switches now used in all switch-gear were first designed by him for the London Electric Supply Corporation in May, 1892, and some of them had been in constant use ever since. Where oil-switches were not worked continually, such as an oil-switch controlling a feeder, he had found that a thin film of oil appeared to get between the contacts, causing a slight sparking to take place, which, if left over any length of time, reduced the surface of the contact and caused heating of the various parts. If it were possible, he would like to see some mechanical means of indicating the exact position of the oil-switch itself, that was, when it was off or on, as, should anything go wrong with the porcelain insulator carrying the actual switch-arm, the man in charge had no notion whether his switch was on or off, as his pilot-lights, which were controlled by the mechanical arrangement of the switch, were lighted. Mr. Partridge had witnessed what might have been a very serious accident from this cause. In some oil-switches he had at present in use, a mechanical contrivance had been actually fitted to the metal arm carrying the current, and indicated its exact position. It might also interest engineers to know that the London Electric Supply Corporation had underground high-tension oil-switches in constant use on the high-tension feeders. By means of them the superintendent of mains could cross-connect or switch-off lengths of feeders, which made the use of these switches invaluable for detecting faults or making joints. Some of these switches were installed in October, 1892, and were still in use and giving no trouble. Signalling arrangements in large stations were very necessary; but Mr. Partridge had not, up to the present, seen a perfect arrangement for this purpose. The oil-switches, synchronizing-lamps, etc., placed alongside the turbines in the St. Denis station formed a very good arrangement; but they should not be controlled by any relay. It gave an opportunity to the engine-driver of seeing exactly what the switch-man was doing, by looking at the instruments placed on this switch-pillar. The main discharger shown by the Author as the "Partridge system of charging," by means of transformers instead of water-resistances, when properly manipulated, caused no rise in pressure, or disturbances. The actual apparatus first designed by Mr. Partridge for the Deptford generating-station in 1892 had been in daily use for the last 14 years, and although mains 7 miles in length were every night and morning switched on and off to a single-phase system on a periodicity of 85, it was impossible to tell

when a main was put on or when it was taken off: which he thought Mr. Partridge spoke for itself. Another advantage of the use of transformers would be for high pressures, say, above 10,000 volts, as it was much easier to wind a transformer for a working-pressure of, say, 15,000 volts than to make a water-resistance. The discharger in question was also arranged so that, if necessary, the two halves of the station could be synchronized and gradually put in parallel or divided up again to separate systems by its use. He had never seen this in use in any other station. He thought that series transformers should, if possible, be always placed between the generator and the main oil-switch: this was not always shown in the diagrams of the Paper. By these means, when the main switch was off, the transformer connected with the generator was made dead. Failure of a series transformer meant a very serious breakdown in the system and a possibility of the high pressure getting on to the instrument-boards. He had not seen any satisfactory means of protection against this, and he would like to know if any engineers had considered the use of high-tension fuses placed on the low-tension windings of these transformers, thereby cutting off the instruments entirely if the high-tension should get through. The use of protective devices on high-tension circuits was a very interesting subject. He had himself devised different kinds of apparatus to work in connection with it; but he had never had very satisfactory results. The use of water-jet resistances might be a way out of the difficulty if coal were cheap. In one of the large stations on the Continent, where they had been installed but abandoned, one feeder when working at a pressure of 10,000 volts would absorb 230,000 units per annum if a water-jet resistance was always connected across its terminals. As it would be necessary to put one of these resistances across each feeder it would render the use of this apparatus out of the question.

Mr. BERTRAND ROWE, of Pittsburg, Pa., observed that in all general Mr. Rowe features the descriptions given by the Author covered the practice followed throughout the United States in large power-installations. The difference between American and European practice lay in the details. One of the most difficult parts of such an installation was the isolating of conductors at terminals, where they connected to oil circuit-breakers and other apparatus. The best American practice for large stations provided that each lead as it left an oil circuit-breaker should be confined to a separate compartment. In many of the switches described in the Paper, the leads of the heavy-duty switches, such as were shown in Plates 1 and 2, were taken out at the top of the switch, where they were not easily isolated on account

Mr. Rowe, of the mechanism. He was glad to learn that European practice seemed to confirm American, in that oil circuit-breakers should be designed to open rather than close by gravity. Another feature in American practice which differed from what was described as European practice, was that, in the United States, the entire control of all electrical apparatus was placed in the hands of the chief operator of a station, and there was no auxiliary control-column provided on the engine-room floor for the use of the steam-engineer, as described on p. 28. In many stations, however, a wattmeter was provided for the convenience of the steam-engineer to enable him to observe the loading of his generators, and a system of signals at each machine connected him with the chief operator. A synchroscope was often provided also, which could be observed by the steam-engineer, this synchroscope operating in parallel with another which was observed by the chief operator. As to the fire-proofing of cables, flame-proof cable was only applicable in stations where conductors could be well insulated from grounds and opposite polarities. This was necessary because the covering was liable to absorb more or less moisture, and if the covering got grounded, and was damp, it was the same as supplying the cable with a grounded sheath. This would rapidly deteriorate a rubber-insulated cable. The flame-proofing was always stripped away from cable-ends and places where the covering must be adjacent to live terminals. The section of copper in bus-bars and conductors varied with the frequency, and American custom was not as conservative as the usual practice mentioned in the Paper. While flat-bolted contact-surfaces were rated at 100 amperes per square inch, the current-density for hard drawn copper was taken at 800 amperes per square inch for a temperature-rise not exceeding 20° C. for continuous-current work. For the same conditions at 60 cycles per second the density should be about 550 amperes per square inch; while for 25 cycles the density should be about 650 amperes per square inch. For threaded contacts 200 amperes per square inch was allowable, reckoning on the cylindrical surface of the threaded portion. The foregoing current-densities would be lower than necessary if the conductor was of such a section that it presented a large radiating surface to the air and was not confined.

Mr. Vogelsang. Mr. MAX VOGELSANG, of Frankfurt-am-Main, expressed his entire concurrence with the Author's general opinions, but drew attention to a few discrepancies which he discovered in them, with special reference to German standard practice. Although the general technical considerations guiding the safe construction of high-tension switchboards were more or less international, the rapidity with which this branch of electrical engineering grew nevertheless led to certain differences in

construction in the various countries. It was not customary in Germany to provide separate oil-tanks for three-phase circuit-breakers, not even in the large sizes, so long as they were built on the well-known and simple principle of only two breaks per pole. It was customary to keep the phases separate—that was, to construct a three-phase circuit-breaker in the same way as three single-phase circuit-breakers—only in those cases where it was necessary to do so on account of exigencies in design such as were present in the case of high-tension switch-gear for 20,000–30,000 volts, and which possessed more than two breaks per pole (namely, six to ten breaks per pole). The design of a circuit-breaker with separate oil-tanks appeared to him to be unsatisfactory, inasmuch as it was certainly more troublesome to look after three oil-tanks (and perhaps empty and fill them) than one oil-tank; and, further, the use of separate oil-tanks introduced unnecessary metallic partitions between the poles, whereby, in comparison with the compactly-built apparatus, there was certainly no increase in safety, whilst, on the other hand, a large and clumsy design was the result. It was also necessary to remember that in practice, should one pole of a circuit-breaker become faulty, it made no difference, as regarded repairs, whether the poles were entirely separate or not. It was, however, very desirable to separate the poles in their common oil-tank by means of wooden or other partitions, at places where direct arcking from pole to pole could occur; but, as already stated, he did not believe that the separation of the poles in independent tanks resulted in a gain in safety. As regarded electrical switch-gear control, the Author described a system which appeared to differ from the usual push-button control so extensively employed both in the United States and in Germany. Both in Germany and in America, where the electrically-controlled high-tension circuit-breaker probably originated, it had always been usual to design the apparatus in such a way that the circuit used in closing the switch was first made by a push contact, and, after completion of the main circuit, automatically broken by the apparatus itself. In the German apparatus this circuit was worked in conjunction with that of the signal-lamps, whereby matters were further simplified in this respect. He was at a loss to discover, from the Author's description of the connections for his apparatus, any advantages compared with what might be called the well-known push-contact system. The "free-handle" system, which was usually recognized as the distinctive feature of a good modern automatic circuit-breaker, did not appear to him to be essential for these large high-tension switches, primarily because they were nearly always fitted with time-relay releases, whereby the switch could never be released the moment it was closed. The relay would therefore have

Mr. Vogelsang.

Mr. Vogelsang. to be disconnected at the moment of making the circuit, which could be effected by arranging the switch-gear accordingly. Perhaps the Author had this in view in the case of the apparatus described. As regarded special cable-charging gear he would like to know whether such apparatus was of sufficient practical value to justify the additional complication which its use in a high-tension system must entail. The Author mentioned two such devices, one with Ferranti liquid-resistances, and the other with transformers. Mr. Vogelsang believed that it would be difficult to prove that either of these fundamentally different systems was necessary or of value, since the theoretical reasons for the adoption of such appliances were, so far, rather deficient. The electrical phenomena which took place when a current was suddenly sent into a dead three-core cable appeared to him to be so complicated as almost to defy theoretical explanation. Practical experience seemed to show conclusively that, provided the cable and the switch-gear were in order, dangerous phenomena did not occur. If, however, the cable or the switch-gear were not in order, he thought that neither theoretical considerations nor cable-charging gear would be of any use. From the Author's description he gathered that the charging-gear could only be used under normal conditions of make and break. Only slight rises of pressure could occur during these relatively simple and harmless operations, and he thought that everybody with experience in high-tension work would concur with him in saying that an element of danger was only introduced if something extraordinary or abnormal occurred. As the Author rightly said in a foot-note, the introduction of modern oil switch-gear minimized to a very large extent the dangers of abnormal rises of pressure as compared with the earlier system of high-tension fuses and exposed cut-outs. The formation of a high-tension arc, whether in switches, fuses, or lightning-arresters, was almost invariably conducive to abnormal rises of pressure, these being most pronounced in the oft-recurring case where the fuses in the several phases did not melt at the same time but one after the other, when the resulting phenomena might be of the most serious description on account of oscillations set up by the arcs, and the destruction of electrical balance in the cables. In his opinion, therefore, oil-switches were the best, as producing the smallest possible arc, and moreover, he considered it desirable to make their action as rapid as possible, and not to waste time in manipulating liquid resistances, etc., as he feared that, for instance, a resistance of this description, from which, owing to faulty handling, half the water had evaporated, would actually be a much more dangerous piece of apparatus than an oil-switch pure and simple. Moreover,

when it was realized that these beautiful devices were not permitted Mr. Vogelsang to act at a time when, theoretically at least, they were most urgently required, namely, when a circuit-breaker acted automatically on a short-circuit, he really could not understand why an installation should be encumbered with apparatus of this description under normal working-conditions. It being desirable to bring about standardization in certain apparently minor details, he would plead this cause in the case of exciter-voltages to firms engaged in the construction of dynamo-electric machinery. This was sometimes really very annoying when generators in the same power-station were built by a number of different firms. One generator might be built for an exciter-pressure of 110 volts, another for 80 volts, and perhaps yet another for 50 volts. True, the choice of a different exciter-voltage might present some advantages as regarded the winding of the generator, but these were really of very little consequence. It was desirable that greater harmony should exist as regarded exciter-voltages, and he would submit that an entire departure from the practice of direct-coupling exciters would be advantageous, this system being adopted by manufacturers partly from mere commercial considerations, and partly in view of the above-mentioned benefits in winding the generators. He had never been enthusiastic about this arrangement, chiefly on account of the obvious fact that the whole generator-set, consisting of exciter, generator, and steam-engine, would be put out of action if anything went wrong with the exciter. For these reasons he considered it advisable to avoid the use of direct-coupled exciters, and, in order to simplify the co-operation of various types of generators, to recommend the adoption of a standard exciter-voltage. The most suitable would probably be 110 volts. The best method would probably be that advocated by the Author, of obtaining the exciter-voltage from rotary converters, and providing accumulators as a stand-by. The lighting-load of the station should then also be taken from the exciter-mains in order to safeguard completely the illumination of the building in case of a serious breakdown. In reviewing the beautiful safety-arrangements for high-tension switch-gear described in the Paper, he would supplement the Author's views by indicating that safety-arrangements for the measuring-instrument transformers were perhaps somewhat neglected. There could be no doubt that, compared with the solicitude with which, for instance, the bus-bars were usually insulated (these consisting merely of a few stout copper rods resting on insulators, and being more or less innocuous) the benefits of precautionary measures were unfairly

Mr. Vogelsang. distributed, as regarded the fixing of measuring-instrument transformers, which, as the Author stated, were relatively more liable to breakdowns.

The Author. The AUTHOR, in reply, entirely sympathized with Mr. Clothier's remark as to the necessity of a strong hand to strike out the superfluous parts and details in switch-gear. There was certainly in many modern stations duplication and even triplication of certain apparatus, and also many instruments that might as well be left out. But the strong hand would have to be that of the engineer who drew up the specification, and not that of the designer who, in many cases, had no voice in the matter, and was often hampered by conditions with which he was entirely at variance. With the object of eliciting a decisive opinion on the practical utility of cable-charging gear, prominence was given to this subject in the Paper. It was of some importance to eliminate, if possible, this cumbersome and costly apparatus, and the objections raised by Mr. Clothier, who first introduced the principle of charging feeder-cables, and Mr. Vogelsang, could give only satisfaction to all who desired the simplification of switch-gear. The views expressed confirmed those put forward by Mr. J. P. Gregory¹ in 1904, and also seemed to confirm general modern practice. In reply to Mr. Partridge, the oil-switches placed near the machines were not controlled by relays. They were non-automatic, but could be released electrically by the operator at the switchboard for reasons stated on p. 29. Contrary to Mr. Rowe's supposition, the apparatus placed alongside the machines was not provided for the purpose of giving the control of the alternators into the hands of the engine-driver under normal working-conditions, but it served the purposes indicated on p. 28, and, as Mr. Partridge observed, was to enable the engine-driver to see what the operator was doing. With regard to the water-jet resistances, these were usually connected with the main bus-bars, and thus only one or two sets per station were required, and the number of units absorbed in comparison with the total output of the station would be insignificant. The main reason for fitting the various poles of large-capacity circuit-breakers with separate tanks was to safeguard against short-circuits. A design of switch on the lines of those shown in Figs. 15, Plate 2, gave, in the opinion of the Author, a very much greater margin of security than one with a tank common to the several poles, which latter arrangement, according to Mr. Vogelsang, appeared to be the German practice even for large sizes.

¹ Minutes of Proceedings Inst. C.E., vol. clix, p. 246.

The free handle was necessary in circuit-breakers in spite of their being supplied with time-limit devices, as the latter might cause the switch to open while the operator still had his hand on the lever. Besides, it was just with large circuit-breakers, such as those shown in Figs. 6, Plate 1, and *Fig. 18* (p. 46), that the application of the principle became imperative. The heavy levers must be rendered independent of the opening mechanism, as otherwise, on operation of the circuit-breakers, they would be thrown over into the open position, and so constitute a certain danger to any person standing near by.

8 January, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President,
in the Chair.

The Council reported that they had recently transferred to the class of

Members.

WILLIAM CRAIG.
GEORGE GARSON.
WILLIAM JOHN HANCOCK.

GEORGE HOBBS.
JOHN MONASH.
WILLIAM WATTS.

And had admitted as

Students.

JAMES ORMISTON AFFLECK.
ARTHUR CHARLES AUSTIN.
The Hon. HUGH TERENCE DE BURGH
BINGHAM.
ROBERT MACKIE BROWN.
GODFREY HUGH BRUNNER, B.Sc. (*McGill*).
HARRY GRAHAME BUTCHART.
PERCIVAL MILLER CHADWICK.
HAROLD ALFRED HUNTER CHRISTIE,
B.A. (*Cantab.*)
NOEL GRAHAM DUNBAR.
WILLIAM GEMMEL FAIRWEATHER, B.Sc.
(*St. Andrews*).

SIDNEY CHARLES GLADWYN.
JOHN ROBERTSON GORDON.
ALFRED GUEST, B.Eng. (*Liverpool*).
DOUGLAS HAY.
GERALD LACEY.
JOHN NAPIER LIST, B.A. (*Cantab.*)
EDWARD GEORGE MANSO DI VILLA.
PERCY TINDELL MAYBURY.
EDWIN VERNY RICHARDS.
FREDERICK ANTOINE ROSE.
ALFRED SAMUEL VINCENT TAYLOR.
OLIVER THORNYCROFT, B.A. (*Cantab.*)
ROY THORNTON TOOGOOD.

The Scrutineers reported that the following Candidates had been
duly elected as

Members.

GEORGE HENRY CHURCH.

| ARTHUR JACKSON.

Associate Members.

CHARLES ANTONY ABLETT, B.Sc. (Engi-
neering) (*Lond.*), Stud. Inst. C.E.
CECIL GUY BARNETT, F.C.H., Stud.
Inst. C.E.
HABEEB BASTA, Stud. Inst. C.E.
ARTHUR TETLEY BRAZLEY, B.Sc. (*Vic-
toria*), B.Eng. (*Liverpool*), Stud.
Inst. C.E.

ROBERT JAMES BOYD, B.E. (*Sydney*).
HAROLD EUSTACE COAD.
WILLIAM ROBERT DAVIDSON.
MALCOLM ELLIOTT-COOPER, B.A. (*Can-
tab.*), Stud. Inst. C.E.
WILLIAM FARRANT.
CHARLES DOUGLAS GEE.
WILLIAM MAURICE GRIFFITH.

Associate Members—continued.

CHARLES WILLIAM HARRIS.	WILLIAM GEORGE MELVIN.
JOHN EDWARD HENSMAN, B.A. (<i>Madras</i>).	ALFRED WILLIAM OKELL, B.A. (<i>Can-</i>
DANIEL PETER HOWELLS.	<i>tab</i> .)
HERBERT RICHARD HYATT.	ARTHUR POPE.
EDWARD ROBERT HOULTON JACKSON,	ROBERT SIMOND RANKEN.
Stud. Inst. C.E.	DOUGLAS HENRY REMFRY.
COSMO REYNOLD JONES.	THOMAS CASSELLS ROSS.
THOMAS JOHN RANSOM KIERMAN, B.Sc.	ALFRED ERNEST RUFFHEAD.
(<i>Engineering</i>) (<i>Lond.</i>), Stud. Inst.	WILLIAM HAMILTON SHORTT, Stud. Inst.
C.E.	C.E.
FREDERICK OSCAR KIRBY, M.Sc. (<i>Man-</i>	HENRY JOSEPH TRIVESS SMITH.
<i>chester and Leeds</i>), Stud. Inst. C.E.	GEORGE HAM WHITEHOUSE.
CHARLES DELACOUR LE MAISTRE.	EDWARD PARNELL WIDDICOMBE, B.A.
JAMES LUSK, B.A. (<i>Cantab.</i>)	(<i>Cantab.</i>)
NORMAN ROWE LYTH.	WILLIAM ROWAN WILSON, B.Sc. (<i>Glas.</i>)
JOHN MCLEAN.	JOHN WOOD.
HAROLD BERTRAM MATHEW, Stud.	HERBERT JAMES YOUNG.
Inst. C.E.	

Associates.

LYNDEN LIVINGSTON MACASSEY, M.A.,	JOHN MACAULAY.
LL.D. (<i>Dubl.</i>)	

(*Paper No. 3651.*)

“The Simplon Tunnel.”

By FRANCIS FOX, M. Inst. C.E.

THE route over the Alps, by way of the Simplon Pass, has existed in one form or other since time immemorial; and, although it originally consisted only of a footpath, yet there are remains of Roman culverts and bridges. Documents dating from the thirteenth and fourteenth centuries show that a toll-bar and a hospice were in existence in those days; but up to the end of the eighteenth century the road was neither safe nor convenient. In March, 1801, soon after the battle of Marengo, the present roadway was commenced by order of Napoleon, and it was finished in September, 1805. The length of the highway is $37\frac{1}{2}$ miles, and its construction necessitated the building of 611 bridges and culverts, together with seven galleries for protection from avalanches, or through rock. The cost was £303,000, in addition to the compulsory labour, or “*corvées*,” of about 700 peasants.

Between the years 1852 and 1893, no less than thirty different proposals for traversing the Simplon by railway were put forward. Of these, two were designed to scale the mountains without sub-

terranean work; and the remaining twenty-eight proposed tunnels of various altitudes and lengths. In 1891 the Jura-Simplon Railway Company brought forward their project, and subsequently, in 1893, the one which has now been completed, namely, a low-level line with easy gradients, as being the only rational method of enabling them to compete with other Alpine railways, and affording a prospect of a return upon the capital required.

Plan.—By adopting the level of the rails of the existing railway at Brigue, all expense of heavy approach-lines and helical tunnels on the Swiss side is avoided; and the railway enters the mountain a few feet above the level of the Rhone. It passes in four places beneath the Simplon roadway, one being under the picturesque village of Berisal; after which point the gallery attains its greatest elevation at about 9·1 kilometres (5·65 miles) from the northern entrance, between the Wasenhorn and the Furggenbaum Pass, and goes through rock and under glaciers at a depth of 2,100 metres (6,888 feet). The greatest depth below the surface attained is 7,005 feet, namely, beneath the slopes and crags of Monte Leone, the highest mountain of the Simplon range, 3,561 metres (11,684 feet) above sea-level: this is by far the greatest depth to which man has ever been below the surface of the earth. After passing under the Lake d'Avino, it proceeds to its southern portal at Iselle, a distance of 19,803 metres (21,657 yards, or 12 miles 537 yards). This length includes two short curves, one at each end; but the "gallery of direction," which for triangulation purposes is driven in a straight line from end to end, is 19,729 metres (21,576 yards) long.

The following Table gives the comparative lengths and altitudes of the Alpine tunnels:—

	Mont Cenis.	St. Gothard.	Arlberg.	Simplon.
Length of tunnel . . .	12,849 m. (14,052 yds.)	14,984 m. (16,387 yds.)	10,240 m. (11,199 yds.)	19,803 m. (21,657 yds.)
Altitude of the highest point above the sea . .	1,294 m. (4,245 ft.)	1,154 m. (3,786 ft.)	1,310 m. (4,299 ft.)	705 m. (2,313 ft.)
Maximum gradient in the tunnel	1 in 45	1 in 172	1 in 66	1 in 143

Not only is the Simplon the longest tunnel in the world, but it is also the lowest in altitude of these four.

The position of the entrance on the south side was determined by two things, namely, the climate, and the extremely narrow character of the valley of the River Diveria. As regards the climate, it was well known that sleighs could reach Iselle every winter, the depth of snow up to

that point not being formidable, whereas a short distance higher up the valley becomes impassable. With reference to the width of the valley, this increases somewhat at Iselle, and although the valley is still very narrow, and consequently inconvenient, it was found possible to arrange there the various buildings and installations necessary at the termination of the tunnel.

Gradients.—The position of the portals having been thus fixed, the gradients also were practically settled. It was obvious, from the experience of previous tunnels, that the gallery must be driven on an ascending incline from both ends, so that the water might flow away by gravitation. In the Mersey tunnel a minimum gradient of 1 in 500 was found to give the water a sufficient flow. In 1893 the same gradient of 1 in 500 was adopted for the northern half of the Simplon tunnel, involving a gradient of 1 in 143 for the southern half, and a length of 526·9 metres (577 yards) has been provided in the middle, for the passing and shunting of trains, by the construction of two complete single tunnels (Fig. 1, Plate 3). At the point of culmination, however, the Brigue gradient of 1 in 500 has been connected with the Iselle gradient of 1 in 143 by a vertical curve of 10,000 metres (497 chains) radius for a length of 80 metres (87·5 yards).

Gross Section.—Instead of making one tunnel for a double line of way, as in the St. Gothard and Mont Cenis tunnels, two single-line tunnels, 17 metres (55·8 feet) apart between centre-lines, with cross oblique passages connecting them at every 200 metres (218·7 yards), were designed. It was arranged that one tunnel only should be built at first, with a parallel gallery, and this gallery is to be enlarged for the second tunnel when, according to the international agreement between Switzerland and Italy, the gross receipts exceed £3,218 per mile per annum. Each tunnel was designed to have a minimum internal area of 23·20 square metres (249·73 square feet), with a width at rail-level of 4·50 metres (14 feet 9 inches), and at the carriage-windows of 5 metres (16 feet 5 inches), the height above rails being 5·50 metres (18 feet $\frac{1}{2}$ inch): thus ample space has been given on both sides and above the train for air, and for carrying out repairs when necessary (Figs. 2, 3 and 4, Plate 3). The importance of providing two single-line tunnels in this case cannot be over-estimated, and experience has fully justified their adoption. In fact, the Author has no hesitation in saying that had not this been arranged originally, the work would have proved impossible to carry out, and would have had to be abandoned for reasons given later on.

Galleries.—Two galleries were excavated, No. 1 forming the present tunnel, and No. 2 being parallel to it, and the latter was

used as the "in-bye" for the fresh air from the outside, which blew the vitiated air from the workings through the last transverse gallery (Fig. 5, Plate 3). Each of the previous "cross cuts" was provided with double doors, so that the air-currents could be regulated in any way desired; but it was found that so much air escaped through them that they have been closed by masonry, with the exception of one such gallery at each kilometre, where a door is provided of sufficient size to allow one man at a time to pass. It was only the most advanced transverse passage that was left open for the air to circulate freely, thus securing good ventilation. These galleries formed the bottom heading, and were kept 500 to 1,000 yards in advance of the "break-ups" and top headings. The second gallery now provides for one of the channels for conducting the water from the springs to the outside of the mountain, and also for the pipes and conduits; and it served for transporting material during construction (Fig. 6, Plate 3). Whenever repairs may require to be executed in the arching of the work without stopping the traffic, they can be far more easily effected in the case of two single-line tunnels than in one of double line; for the trains would be diverted for the time being, and thus the timbering for the repairs would not have to be so arranged as to allow traffic to pass. In the event of derailment of a train, the passing vehicles would not be exposed to the danger of collision; and, finally, where great pressure comes on to the lining of the work, it would be far less in a single-line than in a double-line tunnel, a matter whose great importance has been proved by actual and very anxious experience. In fact, it is the opinion of those connected with the work that it would otherwise have been practically impossible to make the lining strong enough to resist such pressure as was encountered at a point about 4·4 kilometres (2 miles 1,292 yards) from the south entrance. The tunnel is lined throughout with masonry, as it was deemed undesirable to run the risk of any such occurrence as the fall of a block of rock on to the line during traffic. Four different sections of masonry are shown in Figs. 2, 3, and 4, Plate 3; but during the execution of the work far greater thicknesses were found to be necessary, that at 4·4 kilometres (2 miles 1,292 yards) from Iselle attaining 5½ feet of granite blocks (Fig. 14, Plate 3). On the west side of the tunnel, that is, on the right-hand side entering from Brigue, a small safety manhole 7 feet wide is provided at every 50 metres; whilst at every 200 metres the transverse gallery serves as a refuge. In the length of the tunnel, four large rooms are built for the use of the workmen and their tools, trollies, etc.: these rooms are 4 metres (13·12 feet) wide, 3·10 metres (10·17 feet) high, and

6 metres (19·68 feet) long. On the east side, at every kilometre (1,094 yards), a small room, 3 metres (9·84 feet) each way, is provided for signals, and for the junction of the electric cables : it is at these points that by means of electric light the number of kilometres is indicated for the information of the locomotive-drivers. The Author is strongly of opinion that every tunnel exceeding a $\frac{1}{4}$ mile in length ought to be constructed with a room for the men, furnished with a cooking-stove and seats, in order that they may be able to heat their food, and have their meals, protected from the draught and smoke of the tunnel.

Programme.—On the 20th December, 1890, an association represented by Messrs. Sulzer of Winterthur, and Messrs. Brandt, Brandau and Co. of Hamburg, as contractors, presented to the directors of the Jura-Simplon Railway Company the project for piercing a tunnel of low altitude, and in July, 1891, the railway-company handed to the Federal Government definite plans for its construction. Doubts, however, were cast by certain engineering authorities upon the possibility of constructing the tunnel; and, in consequence of this, the Swiss Confederation requested the Governments of Italy, Austria, and England each to nominate an engineer having experience of tunnelling, to form a “commission of experts,” whose business it would be to examine the programme and proposals, and the plans and estimates, and to report to the President of the Swiss Confederation. The Government of Italy nominated the Hon. Giuseppe Colombo, Member of the Senate, and afterwards Minister of the Treasury; Austria appointed Mr. C. J. Wagner, Chief Government Inspector of Railways in Vienna, and the celebrated engineer of the Arlberg tunnel, whilst the British Government nominated the Author. These three engineers sat at Berne for some time considering the plans and estimates, and going into every detail; the proposed systems of drilling and ventilation were laid before them, and, after examining the site of the tunnel and the proposed entrances, they drew up and presented a report to the President and the Swiss Federal Council in July, 1894.

Upon this programme of the engineers and contractors, confirmed by the report of the committee of experts, the tunnel has now, notwithstanding its unique and unprecedented difficulties, been successfully constructed; and it is interesting to find that all the various methods which were devised and proposed for carrying out this work have been employed with the greatest success. Mr. Brandt, whose lamented death occurred soon after the commencement of the works, had had a wide experience on the St. Gothard tunnel, which enabled him to devise and introduce many improvements in

the machinery and installations. His place was taken by Colonel Locher-Freuler, of Zürich, the celebrated engineer who constructed the Pilatus railway, the most daring piece of work of its day: he planned and constructed all the installations at Brigue and Iselle. Considering its importance and magnitude, this work was done with a rapidity which has never been equalled, for the line of access at Brigue was executed in 1 month, and 250-HP. engines were in operation in 3 months, whilst the hydraulic machinery at Brigue and Iselle, aggregating 4,185 HP., was ready in 14 months. Messrs. K. Brandau, Edward Sulzer and Locher-Freuler formed a remarkable combination of financial and mechanical skill and dogged determination, which absolutely refused to admit defeat where so many pronounced the difficulties encountered to be insuperable. Hence it is that Switzerland is proud of the men who have successfully carried through this work, and has conferred upon them, as also upon Mr. Zollinger, Mr. Pressel, Baron von Kager, and Professor Rosenmund, the well-merited degree of *Doctor honoris causa*. Mr. Sulzer has stated in public that, had the geologists been quite accurate in their preliminary investigations and reports, and had they truly and correctly anticipated the dangers and obstacles which were eventually met with in soft rock, the "Great Spring," or river of cold water, the high temperatures and hot springs, and the "creep" or lifting of the floor, no one would have dared to undertake the contract, and the tunnel would never have been constructed.

On the 25th November, 1895, the Jura-Simplon Railway Company, then represented by its President, the late Mr. Ruchonnet, and by Mr. Dumur, signed a convention for the Simplon tunnel at Rome with the Italian Government, and in December of the same year it was ratified by both countries. The estimated cost was 76,010,000 francs (£3,040,400), and towards this the Swiss Federal and Cantonal Governments, with other contributions, subscribed 16,260,000 francs (£650,400), to which must be added contributions from the Italian Government, the Provinces of Milan and Genoa, Novara and Alessandria, and various cities, amounting to 4,000,000 lire (£160,000), thus making a total free gift of 20,260,000 francs (£810,400).

Contract.—Under the contract, dated 15th April, 1898, the first tunnel was to be completed in 5 years and 9 months, a further 4 years being allowed for the enlargement and completion of Gallery No. 2 into a second tunnel; but alterations were made, both in the time, which was extended by 12 months, and in the amount of the contract, which was raised to 78,000,000 francs (£3,120,000). The specification stipulated for excellent ventilation in all the working-

places in the tunnel, and the maintenance of a temperature not exceeding 25° C. (77° F.), the necessary conditions to be obtained by the aid of jets of sprayed water: further, a good supply of drinking-water in all the working-places was to be provided, together with free baths for the workmen, whilst healthy lodgings and good food at low prices were to be placed within their reach. When it is remembered that this specification was in large measure drawn up by the contractors, it can safely be said that the solicitude and care evinced for their workmen has been an object-lesson to the world.

It was intended that half of the tunnel should be built from the Brigue entrance, and the other half from Iselle, so that all the work should be driven on an ascending gradient. Accordingly, the machinery installed at each place was laid out with this object in view; but eventually very considerable modifications had to be introduced. On the 12th August, 1898, the Jura Simplon Company notified Messrs. Brandt, Brandau and Co. of their acceptance of their contract, and next day the necessary land was placed at their disposal.

Geology.—The rock consists chiefly of gneiss, mica-schist, and on the Italian side of antigorio gneiss, but in some places, particularly about 4·4 kilometres (2·73 miles) from Iselle, limestone was encountered. It is lustrous in appearance, commonly known as “sugar marble,” and highly charged with springs of cold water, having a temperature of 11° to 17° C. (52° to 62·6° F.). In the vicinity of this marble the stratification revealed a soft, easily disintegrated micaceous rock, which under the action of water worked into slurry; and it was in this that some of the worst trouble was experienced. So long as the Brandt perforators had good hard rock in front of them, they made splendid progress; but when soft rock was reached, necessitating timbering, the advance naturally fell off, and in some cases excavation by hand had to be adopted. Great pressure was encountered in places where the geological beds were horizontal, and much heavy timbering was required.

Triangulation.—A survey had been made in 1878 in connection with the proposal of that date, and it sufficed for the first few kilometres; but the actual triangulation was entrusted to Mr. Max Rosenmund, Engineer of the Federal Topographical Department, and since Professor of Geodesy at the Federal Polytechnic School of Zürich; and it is due to this gentleman that both levels and lines of this great tunnel have proved to be so accurate. The plan of triangulation comprised Monte Leone, 3,561 metres (11,670 feet) above sea-level, and there were in addition ten other stations, including the

two axis-points; and it was necessary that three of these should be visible from any point of observation. The survey was linked up to the Wasenhorn-Faulhorn line of the geodetic survey, which connects the Simplon astronomical station with the most important points of the Swiss measurement of the degree. This acted as a base-line for the calculation of the length of the tunnel; and it was not re-measured, as the maximum error which was expected was not greater than 0·8 metre (31·5 inches).

The measurement of the angle occupied 41 days, the instrument used, made by Messrs. Kern & Co. of Aarau, having a horizontal circle, 21 centimetres ($8\frac{1}{4}$ inches) in diameter, and a vertical circle of 16 centimetres ($6\frac{1}{3}$ inches). One division of the micrometer-drum represented 4 seconds; and the vertical circle gave direct vernier readings of 10 seconds. The average closing-error of the triangles was 3·1 seconds; and the maximum, which occurred in the steepest sight of $23^{\circ} 40'$, was 8·5 seconds. By introducing corrections for the action of the mountain masses, the mean closing-error of the triangles was reduced to 1·7 second. For the purpose of setting out, an observatory was built at each end near the axis-points; and permanent levels and lines were checked twice a year, the entire work of the tunnel being suspended during 24 to 32 hours for the purpose. A beam of light was projected into the gallery; and the ventilation was so good that it could be seen by the naked eye more than 5 miles "in-bye." Owing to the difference in the refractive power of the cold air outside and of the warm air of the tunnel, the beam of light, which came through a vertical slit in the lamp-screen, was bowed over at the top in the form of a portion of an arch.

Final Measurements.—The following are the final results of the actual measurements. The axis from the north end deviated 110 millimetres ($4\frac{1}{3}$ inches) towards the west; and the axis from the south end deviated 92 millimetres ($3\frac{3}{4}$ inches) towards the east. This gave a total divergence of the two axes of 8 inches, or a maximum from the true line of $4\frac{1}{3}$ inches. The difference in levels proved to be 87 millimetres ($3\frac{1}{2}$ inches). The total length was found to be 79 centimetres (31 inches) less than was anticipated, or almost precisely the error that was expected. In all the Alpine tunnels except the Mont Cenis the length proved to be less than was calculated, namely, the St. Gothard, in 15 kilometres (9·3 miles), 7·6 metres (24·93 feet) shorter; the Arlberg, in 10 kilometres (6·36 miles), 3 metres (9·84 feet) shorter; and the Simplon, in 20 kilometres (12·26 miles), 0·79 metre (2·59 feet) shorter; whereas the Mont Cenis tunnel (13 kilometres, or

7·98 miles), proved to be several metres in excess of the calculated length.

Water-Power.—It was intended that the installations in the valleys of the Rhone and the Diveria should each be of sufficient magnitude to deal with one half of the tunnel; but owing to great delay, caused chiefly by the above-mentioned dangerous ground at 4·400 kilometres (2·73 miles), it was eventually found necessary for the work, as far as 10·376 kilometres (6·448 miles) from Brigue, to be executed from that end.

Full particulars of the water-supply and channels, as also of the Brandt drill and method of working, have been given in a Paper¹ by the Author's son, Mr. Charles Beresford Fox, Assoc. M. Inst. C.E., and it is therefore unnecessary to repeat what is there described, except very briefly.

At both ends of the tunnel, steam installations of three semi-portable engines and boilers were provided, each giving 250 to 300 HP., which were used to work the drills at the earliest possible moment. They commenced operations at Brigue on the 22nd November, 1898, and at Iselle on the 21st December, 1898.

The hydraulic power from the Rhone and the Diveria was put in operation in the autumn of 1899; and from that time the steam-engines only worked occasionally, for a few hours or a few days as required. In 1904 a locomobile was taken to Iselle, and was fixed at 4·4 kilometres to work the pumps for refrigeration.

The water for the hydraulic pumps at Iselle was obtained from a pure spring up the mountain side, whilst at Brigue it was taken from the Rhone. Owing, however, to a considerable quantity of quartz coming with the water from the river during the summer, the water had to be filtered through sand and gravel. In the Brigue installation, the river water was conveyed by gravitation through a ferro-concrete aqueduct, 3,200 metres (3,500 yards) in length from the village of Mörel to Massaboden. Thence it was carried through wrought-iron pipes, 1·60 metre (5·25 feet) in diameter, under pressure, to the turbine-house, having a head of 44·5 metres (146 feet), and furnishing an effective force of 2,225 HP.

On the south side the works were very similar: a pressure-main, 0·90 metre (35·43 inches) in diameter, extended for a distance of 4,210 metres (2·62 miles). Of this length 1,160 metres (1,269 yards) were of cast iron, and 3,050 metres (3,335 yards) of steel. They took

¹ "The Construction of the Simplon Tunnel." Minutes of Proceedings Inst. C.E., vol. cxi, p. 249.

1·146 cubic metre per second (15,130 gallons per minute) from the river with a head of 177 metres (580 feet), and developed 1,960 effective HP. in the turbines. The turbines worked the pumps, which delivered their water at 100 atmospheres pressure, into the hydraulic main traversing the galleries, and up to the advance headings in which the Brandt drills worked, the available pressure at the point of attack being 76 to 90 atmospheres, according to circumstances. Thus the total available power, north and south, was 4,185 effective HP.

The Brandt drill consists of a stretcher-bar (itself an hydraulic ram) mounted on a portable carriage, and provided with three hydraulic engines each actuating a drill. This is $2\frac{3}{4}$ inches in diameter, and can be worked in any direction; it can be advanced or withdrawn at any desired speed, and the changing of the tool can be effected in 10 seconds. The drill is rotatory in its action and non-percussive, being kept up to its work with a pressure of 10 tons; and as the discharge-water is delivered through the centre of the tool to the cutting edges, the dust produced is at once turned into mud, and at the same time the steel is kept cool.

Sanitary Arrangements.—The sad experience of the St. Gothard tunnel called attention to the great necessity for ameliorating the conditions of the employees. In carrying out that work, between 1872 and 1880, no less than 800 of the workmen died, including both the contractor and the engineer, and this enormous death-roll was essentially due to defective hygienic conditions, to the high temperature and small supply of air in the interior of the galleries, to the severity of the climate, and to the sudden transition from heat to cold. In addition to these causes, were the want of proper provision for changing the wet garments of the men, and the dust produced by the drilling-machines. A special disease called miner's anæmia, now better known as "anchylostomiasis," which is characterized by the presence of a small worm, "*dochmius duodenalis*," in the intestines, propagated itself with terrible rapidity in the St. Gothard tunnel-works.

In the Simplon tunnel, which was eminently favourable to the disease, it was absolutely unknown. Excellent arrangements were made for the complete ventilation of the innermost workings and the most advanced galleries, and for every cubic foot of air which was blown into the St. Gothard tunnel, twenty-five were supplied to the workmen in the Simplon. Not only did the ventilating-fans keep up a steady current of air along one gallery and back by the other, but, by an ingenious system of aspirators, a large volume of fresh air was blown into the dead ends of the galleries, which were thus kept perfectly fresh, and the current was strong enough to

blow a man's hat off. In fact, such a thing as vitiated air was unknown throughout the work, and would have been regarded as a slur on the management.

The primary ventilation was effected by fans driven by hydraulic turbines at 380 revolutions per minute, which delivered as much as 8,600,000 cubic metres (303,723,000 cubic feet) of air in about 24 hours, equivalent to 210,920 cubic feet per minute. The secondary ventilation from the aspirators was accomplished in the following manner. From the high-pressure main in Gallery No. 2, conveying water to the drills, a small pipe was led into the open end of a light sheet-iron tube, 15 inches in diameter, and a jet of water, $\frac{3}{8}$ inch in diameter, was directed along this tube, thereby not only drawing in a large volume of fresh air circulating in the primary ventilation from the fans in the tunnel, but also cooling that air very considerably. One of these tubes was found to convey as much as 1,000 cubic feet of air per minute through a length of 160 yards. In an experiment at Winterthur, a similar jet, at a pressure of about 8 atmospheres, was found to cool air, initially heated to 65° C., down to 15° C., a fall of no less than 50° C. (90° F.). Besides the aspirators, a system of water-sprays was established at various points in the tunnel, throwing a spray of cold high-pressure water (10 to 25 atmospheres) entirely across the passages, and these had excellent effect in cooling the air (Figs. 7, 8 and 9, Plate 3).

The Author desires to urge strongly the immense importance, for the progress of work, for the health of the staff and workmen, and for financial interests, of supplying every working-place in a tunnel with an ample volume of fresh air. Much more work is done, the health of all is preserved, and the many indirect economies result in reduced cost. Notwithstanding all his efforts, he has never known the working-face of a "tube" railway, and very seldom that of an ordinary tunnel, to be properly ventilated. He, however, desires to mention the excellent ventilation provided in the cases of the Greenwich Footway tunnel and of the Blackwall, Rotherhithe and other tunnels driven under compressed air, in which a very large volume was forced in between the air-locks and the working-face.

Next in importance to good ventilation were the excellent arrangements for enabling men to change their clothing. At each end of the tunnel, and connected with it by a covered line of railway, was a large building fitted with dressing-rooms and hot and cold douche baths. From the roof of the building, which was heated by steam-pipes, hung 1,500 ropes passing over pulleys, each with its padlock. On the other end of each rope was a hook upon

which the owner could hang all his things, and then, hauling them up to the roof, he left them there during his absence in the galleries. On his return from work, he entered a cubicle where he had his bath, and, having lowered his day clothes, he attached his wet mining garments to the hook and hoisted them to the roof adjacent to the hot pipes, to find them dry and warm on his return to work next day. If his clothes were torn or soiled, they were sent to the laundry on the premises. After changing from his mining into his day clothes, he passed into a restaurant, where he could obtain a substantial hot meal for 4d., and, if he desired, could obtain board and lodging for 1s. 2d. per day. An excellent hospital was provided at each end of the tunnel, fitted with every requisite, and these establishments were generally empty. Good arrangements for "first aid" were also organized.

Welfare of the Workmen.—The Italian miner, even when called upon to work under less favourable conditions, is extraordinarily resistant, owing to his sobriety, his simple life, and, above all, the good qualities of his race. The doctors reported how quickly the miners recovered from injuries and wounds, and the fact that every man was medically examined as to his fitness for the special conditions of his work led in time to those satisfactory results.

Protestant and Roman Catholic places of worship and day and Sunday schools were also established.

Discipline.—The discipline among the workmen was of the highest order, nearly all of them being Italians, and having been through the Army; and so long as they were not interfered with by paid agitators, no difficulty from strikes was encountered, and no malingering or shirking of work occurred. They worked in three shifts of 8 hours each, and as no man stopped work until his successor actually stepped into his place, the boring-machines never ceased operations.

Temperature.—Judging from the experience of former Alpine tunnels, it was anticipated that considerable heat would be encountered. In the St. Gothard, the maximum temperature of the rock being 31° C. (87° F.), the temperature of the air was 33° to 34° C. (91° to 94° F.), but this, owing to the stagnation of the air, was insupportable; whereas in the Simplon, although the temperature of the rock was 54° to 56° C. (129° to 133° F.), that of the air did not exceed 32° C. (89° F.). This was in no way unbearable, in consequence of the large volume of fresh air travelling along the galleries, and the use of the spraying-devices already mentioned.

In order to obtain the best results in refrigeration, it was necessary that the water should be as cold as possible, and conse-

quently the pipes had to be lagged in order to exclude the heat of the gallery.

The insulation of 10-inch pipes for a distance of 5 to 6 miles involved a difficult problem. The husk of rice was for a time used as a non-conducting material, but, owing to stray grains of rice germinating, it had to be roasted. Then the customs-authorities, finding this worthless material was being used, charged a high rate upon it coming from Italy, and it had to be abandoned. Finally, charcoal was employed with excellent results, the water being delivered at its destination with a rise in temperature of only 4°C . ($7\cdot2^{\circ}\text{F}$.).

During the advance of the galleries, horizontal holes, $1\frac{1}{2}$ metre long, were drilled in the side walls at intervals of 1,000 metres (1,094 yards), and in these thermometers were placed for registering the temperature of the rock. To avoid breakage from the blasting, these holes were necessarily a little in rear of the actual face, and to this extent an element of error was introduced; but this has been corrected as far as possible in Fig. 10, Plate 3, in which the temperature-curve is given below the section of the Alps, with the corresponding curve for the St. Gothard tunnel. The temperature of the rock gradually falls as soon as the excavation has passed any given point, as shown graphically by the dotted curves of the two series of observations on each side of the centre, of March 1903 and 1904. The maximum temperature was 56°C . (133°F .), in proximity to the maximum depth of tunnel (7,005 feet).

At the southern or Iselle side of the Alps, the temperature of the rock followed approximately the section of the mountains until a distance of about 2,200 metres (2,406 yards) was reached. Then, as the tunnel advanced, the rock-temperature began to diminish, and in the region of 4,000 metres (4,374 yards) it fell rapidly, until at 4,400 metres (4,812 yards) it attained the lowest reading recorded. At this point the "Great Spring" was struck, having a flow of 800 litres per second (10,564 gallons per minute), and it was evidently owing to this volume of cold water that the temperature fell. The first outburst of water was at a very high pressure, estimated at 42 kilograms per square centimetre (600 lbs. per square inch). Now, however, it issues at atmospheric pressure, and has a temperature of about 18°C . (64°F .) The conditions in the advanced headings, where hot springs were encountered, produced higher temperatures of the air and water travelling down the galleries from the feeders. Thus the dotted line giving the temperatures of March, 1904, on the northern section shows a retardation of the cooling of the rock between 2.6 kilometres

and 8 kilometres, and between 1 kilometre and 2.6 kilometres; and, as shown in the diagram, the instruments registered higher readings than was initially the case (Fig. 10, Plate 3). A similar result occurred on the southern section, between the entrance and 4.4 kilometres.

Obviously, when studying the depth-temperature curve of the earth's surface, the phenomena at 4,400 metres from the Italian entrance must be neglected, on account of the exceptional agencies producing the result. The deductions are influenced by many other disturbing factors which modify the results more or less, such as the inclination of the strata, and the nature of the rock. Assuming, however, that at a depth of 10 metres below the snow-clad summits of the high Alps a uniform temperature of zero C. (32° F.) may be expected throughout the year; then, out of a total depth of 2,135 metres (7,005 feet), 2,125 metres correspond with a difference of temperature of 54.3° C. (97.9 F.). This represents a temperature-gradient of 1° C. per 39 metres (1° F. for each 71.5 feet).¹ Probably the observations between 8 kilometres and 13 kilometres furnish the most trustworthy average of the results; and this selection gives a relation between depth and temperature of 37 metres per degree Centigrade, or 67.5 feet per degree Fahrenheit.

The Advance.—Fig. 11 shows the rate of progress, both in driving the galleries and in completing the masonry. It was anticipated that the completion of the masonry would be approximately 1 kilometre in rear of the advanced headings, and that the piercing of the Alps would be accomplished about November, 1903, whereas it really took place on the 24th February, 1905; and that the arching would be completed about March, 1904, the actual date being September, 1905. The diagram shows that excellent progress was made in the gallery on the Brigue side, and that the middle of the tunnel was reached nearly 6 months ahead of the programme; but, from that point onwards, difficulties and delays occurred, chiefly due to hot springs and from having to drive down-hill.

On the Iselle side, work went well until 4,400 metres (2.734 miles) was reached. Before this it was noticed that the temperature of the rock had rapidly fallen from 33° C. (91.4° F.) to 13° C. (55.4° F.); and suddenly, and without warning, the "Great Spring" was met with. This stopped the advance for about 6 months, up to March, 1902, by which date the soft ground at this point had been traversed, and hard rock again reached. Again good progress was made until September, 1904, when hot springs

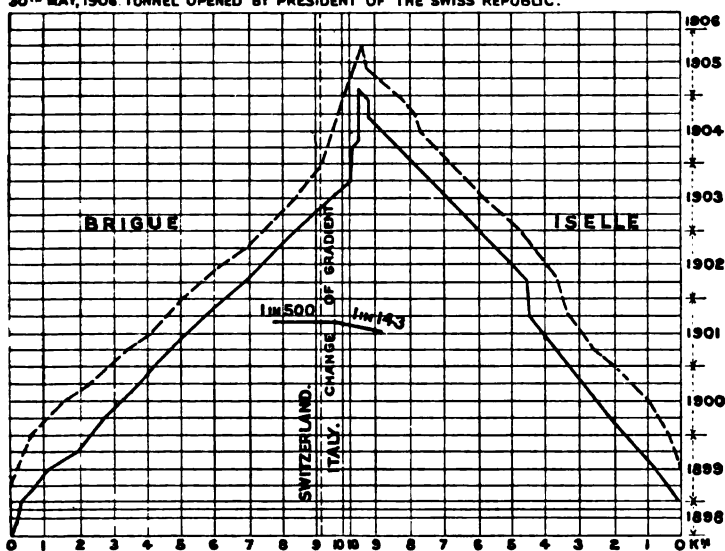
¹ Proceedings Inst. C.E., vol. lviii, p. 392.

were encountered at 9,110 metres (5·659 miles), having a temperature of $45\cdot4^{\circ}$ C. ($113\cdot7^{\circ}$ F.). In order to suppress the heat, a pumping installation was established in the tunnel at 4,400 metres (2·734 miles); and pipes were laid along the gallery, by which cold water was forced up the gradient to the hot region. For working these pumps, a small turbine, driven by the water supplying the drills at a pressure of 100 atmospheres, was at first employed; but as the quantity of water was insufficient for both purposes the locomobile referred to on p. 69 was installed. Jets

Fig. 11.

25th JANUARY, 1906. COMPLETION OF PERMANENT WAY.

30th MAY, 1906 TUNNEL OPENED BY PRESIDENT OF THE SWISS REPUBLIC.



1st AUGUST 1896. COMMENCEMENT OF WORKS.

22nd NOVEMBER, 1896. COMMENCEMENT OF MECHANICAL BORING. 21st DECEMBER, 1896.

— PROGRESS OF ADVANCE GALLERY. COMPLETION OF MASONRY.

TOTAL LENGTH OF TUNNEL 19,803·1 K^m = 12 M. 537 Y^{ds}

DIAGRAM SHOWING PROGRESS OF ADVANCE GALLERY, AND COMPLETION OF MASONRY FOR TUNNEL NO. 1.

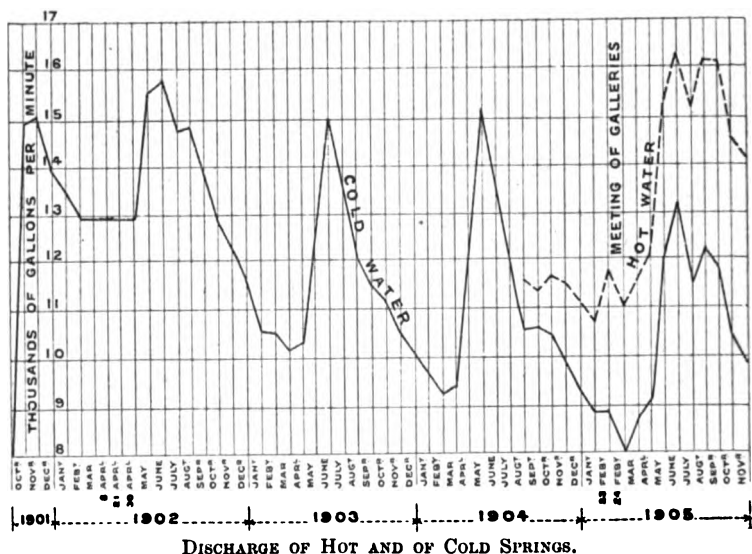
of cold water were then thrown into the fissures from which hot water was escaping, whereby the temperature was lowered to such a point that the miners were able to stand it.

Springs.—Fig. 12 shows by a full line the flow of cold springs into the workings from September, 1901, to December, 1905, and, by a dotted line, the inflow of hot springs. The maximum discharge of cold water was 1,294 litres per second (17,081 gallons per minute), and the maximum discharge of hot water 328 litres

per second, (4,330 gallons per minute). The maximum flows of cold water occur at the times of melting of the Alpine snows. The volume of 1,149 litres per second (15,158 gallons per minute) in November, 1901, was doubtless due to the first tapping of the underground reservoirs.

Analyses.—The water was frequently analysed by chemists on the spot; and samples taken from a hot spring situated at a point between 9·1 and 9·4 kilometres from the Italian end were analysed in England. This spring discharged water at the rate of 230 litres per

Fig. 12.



second (3,036 gallons per minute), having a temperature of 45·9° C. (114·6° F.). The mineral constituents were as follows:—

	Grammes per Litre.	Grains per Gallon.
Silica	0·0132	0·71
Alumina and ferric oxide	0·0022	0·16
Calcium oxide	0·4910	34·37
Strontium oxide	0·0030	0·21
Magnesium oxide	0·0655	4·59
Potassium oxide	0·0050	0·35
Sodium oxide	0·0086	0·60
Carbon dioxide (combined)	0·0267	1·87
Sulphur trioxide	0·8000	56·00
	1·4122	98·86
Combined water and loss	0·1098	7·68
	1·5220	106·54

A trace of lithium was also present. No barium, cæsium, or rubidium could be detected with the spectroscope. An examination of the gases expelled by boiling the water, showed it to contain only the ordinary constituents of the atmosphere. The complete absence of chlorine is believed to be unique, and seems to indicate that the water was possibly entirely plutonic, having never been on the surface of the globe.

To provide for the escape of the water from the springs, a culvert, lined throughout with masonry or concrete, has been made in Gallery No. 2, the depth being 0·50 metre (19·68 inches) and the width 0·60 metre (23·62 inches); and in Tunnel No. 1, in order to provide for the "Great Spring," the ordinary drain has been enlarged from the point where the spring was encountered, 4,400 metres (2·734 miles), to the outlet at Iselle, the size being 0·70 metre (27·56 inches) in width, with a depth of 0·80 metre (31·5 inches).

Excavation of the Rock.—The actual commencement of excavation was made by miner's pick at Brigue on the 1st August, 1898, and at Iselle on the 16th August, 1898, the Brandt drill being started at Brigue on the 22nd November, and at Iselle on the 21st December, 1898. The southern end of the tunnel was 12 miles from the railway, up a steep roadway; and all appliances and materials had to be brought this distance.

The meeting of the galleries took place on the 24th February, 1905, thus giving a total of 2,392 days. Without making allowance for Sundays, saints' days, and holidays, nor for those occasions on which work was suspended for verification of the axis, or by accidents or strikes, the average daily advance at each face was 4·175 metres (13·69 feet), including several months of hand-drilling. Allowing only for the actual days on which the boring-machines worked, the progress was 5·32 metres (17·45 feet) per day at each face, a result never attained on any other tunnelling work in the world. The Brandt boring-machines used a maximum of 1,000 drills in a day, the number of hand-drills in the same time being 10,000, with a consumption of 760 kilograms (1,675 lbs.) of dynamite, and an output of 450 cubic metres (589 cubic yards) of rock. Up to the date of the meeting of the galleries, the amount of material excavated was 940,000 cubic metres (1,229,500 cubic yards). The number of holes drilled by the machines was 140,000, aggregating in length 200 kilometres (124·3 miles); and the number of holes drilled by hand was 3,600,000, with a consumption of 2,000,000 drills. The total quantity of dynamite used was 1,520,000 kilograms (1,496 tons), all of which had to be carried from the

dynamite-trains up to the working-faces on men's backs, with innumerable precautions.

The two Tables in Appendix I give typical days' work: one is satisfactory, with an advance of 10·2 metres (33·46 feet) in the 24 hours; the second is unsatisfactory, giving a progress of only 4·3 metres (14·10 feet).

The following statement of a week's work, taken haphazard, will give an idea of the progress:—

	North Side from Brigue.		South Side from Iselle.	
	Metres.	Feet.	Metres.	Feet.
1903, July 12	6·80	= 22·30	3·10	= 10·17
" " 13	6·30	= 20·66	4·30	= 14·10
" " 14	6·50	= 21·33	3·70	= 12·14
" " 15	7·30	= 23·95	5·20	= 17·06
" " 16	7·50	= 24·61	6·50	= 21·33
" " 17	7·20	= 23·62	7·40	= 24·28
" " 18	8·50	= 27·89	7·30	= 23·95
Total	50·10	164·36	37·50	123·03

Pressure of the Rock.—In November, 1901, the advanced gallery on the Italian side entered, at 4·422 kilometres (2·748 miles), a formation consisting of calcareous mica-schist entirely decomposed; the drills had to be withdrawn, and the work proceeded by hand. Heavy and close timbering of the entire gallery, on both sides, as well as on roof and floor, had to be done immediately; and although whole timbers were used they were completely crushed, and for the time the heading was lost. The miners were withdrawn, and a fresh start was made by inserting heavy, rolled steel beams (16 inches deep) bolted together, with balks of pitch-pine 20 inches by 20 inches between them; but the pressure deformed this girder-work, shearing the bolts, and crushing the timber into splinters. As a last resource, the space between the beams was speedily rammed full of quick-setting concrete, and this held (Fig. 13, Plate 3). The wagon-road, however, had been maintained, and access was secured for the drill to go on ahead; and thus the advance, after a delay of 6 months, was resumed. The lining of this portion of the tunnel was a matter of the greatest difficulty; but at last, after 18 months' work, at a cost of £1,000 per yard, the permanent tunnel was made secure, being lined with granite blocks throughout the sides, arch, and invert (Fig. 14, Plate 3).

Working Down-Hill from the Brigue Side.—In consequence of the delay caused by the difficulties described above, the Swiss headings had reached the culminating point, 9,573 metres (5 miles 1,670 yards), which had always been arranged to be the extreme boundary

of the workings from that side. In order, however, to save time, it was decided to drive forward as far as possible on a slightly rising gradient, until the top of the future tunnel was reached, by which a point at 9,979 metres (6 miles 350·4 yards) was attained on the 10th October, 1903, or an advance of 407 metres (445 yards) (Fig. 15, Plate 3).

It was now impossible to go on further on an upward incline; and it was decided to drive down-hill, on a gradient of 1 in 40, in order to meet the miners coming up-hill from the Italian end; and thus the very problem which the ascending gradients had been planned to avoid had to be faced (Fig. 15). On inserting an arm into a bore-hole in the rock, the heat was unbearable, the maximum temperature then met with being 56° C. (133° F.). As the galleries were driven down-hill, the hot springs followed; and the boring-machines and miners were standing in a sea of hot water. This for a time was pumped out over the apex of the tunnel by centrifugal pumps fixed on travelling carriages; but at last, at 10,151 metres (6 miles 541 yards), it was found impossible to continue going down-hill. Nevertheless time had to be saved; and as the height of the finished tunnel would be about 14 feet above the top of the gallery, it was arranged that the heading should, if possible, be continued; and to effect this, it was driven on an ascending gradient of 1 in 1,000 (Fig. 15).

Meanwhile, strong iron doors were fixed in both headings at 10,129 metres (6 miles 517 yards), which could be closed in case of necessity, so as to hold back the hot water. As, however, the actual pressure which would be encountered was unknown, a relief main with necessary valves was provided, which delivered the hot water over the apex of the heading at 9,573 metres (5 miles 1,670 yards). From these iron doors the work was continued under the greatest difficulty, the hot springs in some cases accompanying the miners for a distance of 40 metres (43·74 yards); but with great courage and determination, a point at 10,382 metres (6 miles 794 yards) was reached, being a further advance of about 250 metres (273 yards). By means of centrifugal pumps not only was the hot water ejected from the advance heading but cold water was thrown into the fissures. The quantity of hot water amounted to 1,188 gallons per minute, and absorbed 1,350 calories per second, or 65 per cent. of the refrigeration produced. A very hot spring of 528 gallons per minute, encountered on the 18th May, 1904, combined with an accident to the water-conduits outside the tunnel at M^orel, compelled the miners to retire, and the work on the north side ceased. The iron doors were closed, and the portion south of

them filled with hot water; but the bottom heading, in virtue of its rising gradient, had become a top heading. By the closing of the iron doors, work in the tunnel on the north side of these doors could be proceeded with; and the arching to this point was thus finished. All progress, however, in the advancement of the gallery was arrested; and it was again prophesied, by those who had failed to realize the determination of the men who had the work in hand, that the tunnel was now impossible, and could not be completed. Just before this cessation of work occurred, the engineers on the Brigue side, who were verifying the axis on a Sunday morning when perfect silence reigned in the solitude of the tunnel, heard the drilling-machines at work on the Italian side, when there still remained 1,000 metres (1,094 yards) to be perforated.

Italian Advance.—All hopes were now centred on the Italian advance; but although the miners had the great advantage of an ascending gradient of 7 per 1,000 (1 in 143) to free them from water by gravitation, the temperature and the hot springs became well nigh unbearable. In Gallery No. 1, which in September, 1904, reached a point (marked E in Fig. 16, Plate 3) 9,141·4 metres (5 miles 1,197 yards) from the portal, a hot spring of 1,400 gallons per minute, at a temperature of 116·6° F., was encountered, and stopped all the work, the air of the headings being 100·4° F. A spray of cold water at 50° F. and of 1,056 gallons per minute was established, supplied by pumps at 4·400 kilometres (4,812 yards), and this reduced the temperature to a bearable point. The system, already described, of throwing jets of cold water into the fissures from which hot water was flowing, had also been introduced, and thus a reduced temperature of the water was attained which would not injure the men. The headings, which were in mica-schist, had to be heavily timbered, and an attack was made in Gallery No. 2, with the object of taking the hot spring in the rear, where fortunately hard limestone was met with which assisted the miners (Figs. 16 and 17, Plate 3). Transverse gallery No. 45 was successfully reached, and a point at 9·183 kilometres (5·706 miles) was attained. The Brandt machine then continued to work on at the advance in Gallery No. 1, while the other two headings, marked D and E, were advanced by hand-labour, one working northward, the other southward, until a junction was effected, which enabled the advance to be pushed forward with great vigour.

On the 12th February, 1905, the remaining diaphragm to be pierced was 54·6 metres (59·75 yards); and on the evening of the 23rd February this had been reduced to 5 metres, or an advance of nearly 50 metres (55 yards) in 11 days. A spring of water of 330

gallons per minute and 112° F. was encountered on the floor of Gallery No. 1 from Iselle: at the same time a signal came from Brigue to the effect that the gauge on the iron door indicated a reduced pressure on the imprisoned water; and the necessary arrangements were at once made to allow the escape of the coming flood by Gallery No. 2.

On the 24th February, at 6 o'clock in the morning, the incoming shift of men, with the officials who intended to assist at the final "holing through," were unfortunately delayed by their train being derailed. This was announced by telephone to the men at work at the face, who at once expressed their willingness to continue their labours. At 7.20 a.m. the final charges were exploded in the roof of the gallery, 9,385 metres from the southern portal, producing an aperture 2.6 metres (8.53 feet) in length and 0.80 metre (2.62 feet) in width, Mr. Bacilieri being the only official and engineer actually present. Immediately a large volume of hot water rushed out, which took $\frac{1}{2}$ hour to escape. It was necessary for all the men to leave the tunnel, the condition of affairs being much intensified by the stoppage of the engine pumping in cold water. This meeting of the headings at once proved the extreme accuracy with which the works had been executed, but it lacked the fervour and delight usual on such occasions, as in this case it was a meeting of miners on one side and hot water on the other. The last 245 metres of the gallery had occupied nearly 6 months in execution, owing to the unprecedented difficulties encountered.

Creeping of the Floor.—The rising of the floor occurred in several places, even in solid rock, showing the tremendous pressures existing; and it became necessary to construct masonry inverts for a very considerable distance, which caused much delay.

Quarterly Reports.—It is certain that such reports as those issued every 3 months have never been given on similar work before; they constitute a complete history of the technical and engineering details, and give the most minute information. The Author would refer members to these reports¹ as illustrating the care with which every item was considered, and as showing how carefully every particular was registered for guidance and future reference. Appendix II is a diary of the progress of the tunnel, as gathered from these reports, twenty-nine in number.

Opening of the Tunnel.—The first train passed through on the 25th January, 1906, and on the 19th May the King of Italy traversed the tunnel in a special train, meeting the President of

¹ A complete set is in the Library of the Institution.—SEC. INST. C.E.
[THE INST. C.E. VOL. CLXVIII.]

the Swiss Republic at Brigue, who returned the compliment by travelling with the King to Domo d'Ossola.

On the 30th May three long passenger-trains, containing 850 guests, including the Swiss President, Mr. Forrer, and his Ministers, made the passage of the tunnel, and were received at all the stations along the route with great respect and rejoicings. On the platform at Brigue there was a Simplon Pass diligence and two snow-sleighs for luggage, with a large placard over them bearing the inscription *Morituri te salutant.*

Ventilation and Temperature during traffic.—The trains mentioned above were hauled by steam, and as they passed through within 10 minutes of each other the conditions of ventilation could not be expected to be so good as with electric traction, especially as the spraying of the air with high-pressure water was not in operation. The volume of air blown in at Brigue was 169,000 cubic feet per minute, in addition to a further quantity of 50,000 cubic feet per minute forced in at Iselle by Gallery No. 2, and passing out by Tunnel No. 1. The ventilation was excellent, and although the temperature in the middle of the tunnel was high, as is shown by the observations given below, the air was fresh.

The train from Brigue to Iselle travelled with the current, and made the passage in 20 minutes, the speed being 36·75 miles per hour. The temperature of the air outside the tunnel at Brigue was 84° F., at 1 kilometre inside the tunnel 82°, and at 10 kilometres 87·5°, which continued to the southern portal; whilst the temperature of the air outside at Iselle was 90°. Traversing the tunnel in 22 minutes in the opposite direction against the current, and, consequently, meeting the accumulated heated air immediately on entering the tunnel, the results were as follows. The temperature in the open air at Domo d'Ossola was 90°, inside the tunnel at Iselle 83° F., at 1 kilometre from the south entrance 90°, at 7 kilometres 90°, at 10 kilometres 85°, at 15 kilometres 75°, and at 19 kilometres 65°; whilst outside the tunnel, at Brigue, the temperature was 78°.

Cost of Tunnel.—Though the cost of the tunnel has not yet been fully ascertained, it is believed to have been about £3,200,000, equivalent to £148 per lineal yard.

Debris from the Tunnel.—It is unfortunate that no arrangement was come to between the tunnel-authorities and the Italian government for the debris to be made use of in the construction of the approach-line, for it has been tipped into a large spoil-bank on one side of the valley, while extensive quarries were excavated to supply material for the embankments of the railway.

Electric Traction.—The tunnel is equipped throughout for electric

traction on the three-phase system with overhead conductors, and the electric locomotives have been at work for some time. Whether from the moisture in the air resulting from the spraying of water, or from other causes, the insulation in two of the motors out of five has, unfortunately, broken down. This is being investigated, and it is expected that the electrical haulage of trains will be resumed shortly. In the meantime the traffic is being satisfactorily worked by steam-locomotives.

In conclusion, the Author desires to draw attention to the excellent order and neatness which characterized the whole undertaking. Within the boundaries of the installations at both ends of the tunnel no rubbish of any sort was allowed to accumulate. Everything was in its place, and men were constantly employed in sweeping the ground and keeping it clean and tidy. In this respect the undertaking compares favourably with many engineering works in this country; and it constitutes, from every point of view, an excellent illustration of an engineering project efficiently carried out.

In addition to the names of Dr. Brandau, Dr. Sulzer-Zeigler, Dr. E. Locher-Freuler, Dr. Pressel, Dr. von Kager, and Dr. Rosenmund, the Author desires to mention Dr. Haeussler and Mr. Beissner as having been associated with them in the enterprise. The names also of Mr. Colomb, Director of the Federal Railways, and Mr. Zollinger, Chief Engineer of the Company, will ever remain connected with this great work.

The number of men who lost their lives in the execution of the tunnel was sixty; and to them, in May 1905, a monument was erected at Iselle, which it is impossible to read without rendering well-deserved homage to their memory.

The Paper is accompanied by thirteen drawings and tracings, from which Plate 3 and the figures in the text have been prepared.

APPENDIX I.

TABLE I.—SIMPLON TUNNEL (ISSELLE SECTION).
Mechanical Boring. Brandt Drill.

Report, 28 June, 1902.

Position of Works.	Attacks.	Progress.			Time Occupied.			Men Employed.				Mines.			Material Used.				Observations.
		Distance from Front of Attack to Portal.	Progress.	Section.	Drilling.	Clearing Debris.	Time Lost.	Total.	Superintendent.	Mechanics.	Drillers and Chargers.		Boys, &c.	Total.	No. of Drills Used.	Drills Disabled.	Dynamite Consumed.	Drills at Work.	
Gallery	No. 168	Metres. 4,788.8	..	Sq. Metres. ..	..	0 ⁰⁰	Nil	Hrs. 0 ⁰⁰	..	..	..	..	No. ..	Metres. ..	..	Nil	Eg. ..	..	{End of Attack No. 168.
"	169	4,790.2	1.4	5.2	0 ⁰⁰	2 ⁰⁰	"	3 ⁰⁰	1	7	10	..	18	101.50	15.0	12	33.0	3	
"	170	4,791.4	1.2	..	2 ⁰⁰	3 ⁰⁰	"	2 ⁰⁰	..	..	..	..	..	101.20	12.0	14	35.5	3	
"	171	4,792.6	1.2	..	4 ⁰⁰	6 ⁰⁰	"	3 ⁰⁰	1	6	9	3	19	101.20	12.0	13	34.5	3	
"	172	4,793.9	1.3	..	7 ¹⁰	9 ⁰⁰	"	2 ⁰⁰	..	..	..	..	..	101.30	13.0	17	34.5	3	Rock, anhydrite.
"	173	4,795.2	1.3	..	10 ³⁰	10 ³⁰	"	3 ⁰⁰	..	..	..	..	..	101.40	14.0	11	31.0	3	Compact.
"	174	4,796.4	1.2	..	11 ⁴⁵	13 ¹⁵	"	2 ⁰⁰	1	6	10	1	18	111.40	15.4	10	32.0	3	
"	175	4,797.7	1.3	..	15 ⁰⁰	16 ³⁰	"	3 ⁰⁰	..	..	..	..	..	111.40	15.4	11	32.5	3	
"	176	4,799.0	1.3	..	17 ⁴⁵	19 ¹⁵	"	2 ⁰⁰	..	..	..	..	..	111.40	15.4	12	32.0	3	{Clearing away of rock of Attack No. 176 not completed.
					19 ¹⁵	21 ¹⁵	"	2 ⁰⁰	..	..	..	..	..	111.40	15.4	12	32.0	3	
					21 ¹⁵	22 ⁴⁵	"	2 ⁰⁰	3	19	29	4	55	831.319	112.2	100	Nil	265.0	3

TABLE II.—SIMPLON TUNNEL (ISMLE SECTION).

Mechanical Boring. Brandt Drill.

Report, 21 July, 1901.

Position of Works.	Attacks.	Progress.			Time Occupied.			Men Employed.					Mines.			Material Used.				Observations.		
		Distance from Front of Attack to Portal.	Progress.	Section.	Drilling.	Clearing Debris.	Time Lost.	Total.	Superintendent.	Mechanics.	Drillers and Chargers.	Timbering.	Boys, etc.	Total.	Per Attack.	Average Depth.	Total Length per Attack.	No. of Drills	Drills Disabled.		Dynamite Consumed.	Drills at Work.
Gallery	No. 51	Metres. 4,068.3	..	Sq. Metrs. ..	..	0** 0 <u>15</u>	Nil	Hrs. 0 <u>15</u>	..	..	..	..	No. ..	No. ..	Metrs. Metrs. ..	..	..	..	Kg. ..	..	{End of clearing away rock of Attack No. 51.	
"	52	4,069.3	1.0	4.50	0 <u>15</u> 3 <u>30</u>	3 <u>30</u> 6 <u>30</u>	"	6 <u>15</u>	1	7	9	1	1	19	9	1.2	10.80	66	"	28.0	3	{Rock. Antigorio Gneiss (very hard)
"	53	4,070.4	1.1	"	6 <u>30</u> 11 <u>00</u>	11 <u>00</u> 14 <u>30</u>	"	8 <u>00</u>	1	6	9	..	1	17	9	1.3	11.70	65	"	29.5	3	{Several springs in roof.
"	54	4,071.5	1.1	"	14 <u>30</u> 17 <u>30</u>	17 <u>30</u> 20 <u>30</u>	"	6 <u>00</u>	1	7	9	1	1	19	9	1.2	10.80	82	"	25.0	3	{Clearing away of rock of Attack No. 55 not completed.
"	55	4,072.6	1.1	"	20 <u>30</u> 23 <u>30</u>	23 <u>30</u> 24 <u>00</u>	"	3 <u>30</u>	1	7	7	1	1	17	9	1.2	10.80	65	"	28.0	3	
Gallery		4,072.6	4.3	4.50	13 <u>45</u>	10 <u>15</u>	Nil	24 <u>00</u>	4	27	34	3	4	72	36	1.225	44.10	278	Nil	110.5	3	

APPENDIX II.

SIMPLON TUNNEL. DIARY OF PROGRESS.

No.	Date of Quarterly Report.	Progress.		Remarks.
		North Side from Brigue.	South Side from Iselle.	
		Metres.	Metres.	
1	To Dec. 31st, 1898	333	76	Installations commenced on north side, Aug. 1, 1898. Drilling by Brandt drill, Nov. 22nd, 1898.
2	„ Mar. 31st, 1899	470	288	
3	„ June 30th, „	490	331	Installations commenced on south side, Aug. 16, 1898. Drilling by Brandt drill, Dec. 21st, 1898.
4	„ Sept. 30th, „	544	438	
5	„ Dec. 31st, „	463	433	Death of Mr. Alfred Brandt, Nov 29th, 1899. Appointment of Col. E. Locher.
6	„ Mar. 31st, 1900	470	428	
7	„ June 30th, „	482	400	
8	„ Sept. 30th, „	483	376	
9	„ Dec. 31st, „	384	380	Permanent ventilation commenced Mar. 18th.
10	„ Mar. 31st, 1901	574	462	
11	„ June 30th, „	502	367	
12	„ Sept. 30th, „	538	420	
13	„ Dec. 31st, „	602	31	The "Great Spring" struck at 4,400 metres from south entrance, causing great delay; timbers crushed, girders bent; finally surmounted by filling the spaces with concrete. Volume of water issuing at south end 10,564 gallons per minute.
14	„ Mar. 31st, 1902	549	15	
15	„ June 30th, „	533	343	
16	„ Sept. 30th, „	471	575	
17	„ Dec. 31st, „	581	498	
18	„ Mar. 31st, 1903	462	471	
19	„ June 30th, „	496	436	
20	„ Sept. 30th, „	523	509	
21	„ Dec. 31st, „	194	477	Hot springs and high temperatures encountered at Brigue face.
22	„ Mar. 31st, 1904	33	430	
23	„ June 30th, „	199	537	Work suspended at Brigue face.
24	„ Sept. 30th, „	..	391	
25	„ Dec. 31st, „	..	52	Hot springs encountered at south face. Galleries from north and south met, Feb. 24th, 1905.
26	„ Mar. 1905	..	191	
27	„ May 19th, 1906	..	..	Tunnel traversed by King of Italy and President of the Swiss Republic.
28	„ May 30th, „	..	..	
29	„ June 1st, „	..	..	Opened by President of the Swiss Republic. Opened for public traffic.

Total length of gallery, 19,729 metres.

Total length of tunnel, 19,803 metres.

Discussion.

The PRESIDENT, in proposing that the thanks of the Institution The President. should be given to the Author for his Paper, remarked that it was suggested sometimes that in the world romance was dead; but certainly, after hearing the account of the construction of the Simplon tunnel, romance in engineering must be admitted to be as alive as ever. What with the brave fellows engaged on the work finding first a lake of cold water and then a lake of hot water, and the final struggle between the miners and the imprisoned hot water—a struggle which had come so near to being a tragedy—the whole undertaking was apparently as full of romance as it was of energy, perseverance, and skill, from the very beginning. The Institution was greatly indebted to the Author for the very clear and interesting account he had given. A letter had been received from the General Direction of the Swiss Federal Railways, which was really a contribution to the discussion, and he would quote from a translation of it one or two passages which he felt sure the members would be glad to see recorded in the Proceedings. After a few introductory words the letter went on to say—

“As the personality of the Author would have led us to expect, this memoir is one of the most interesting and most complete that we know of on the works connected with the piercing of the Simplon, and we can accord to it nothing but praise and thanks so far as our administration is concerned . . . The only addition to the information which we should like to suggest is that we strongly desire that the members of the Institution should learn from Mr. Fox himself that the ventilation in the tunnel continues to be excellent, thanks chiefly to the electric traction which has been put into operation and now works to general satisfaction. Several newspapers, particularly in England, announce periodically, on the strength of information which has been misunderstood, that the temperature in the tunnel is intolerable and that the arch has given way in places. These statements are erroneous, for they confound tunnel No. 1, through which the trains pass and which is in perfect condition, with tunnel No. 2, which is not finished and which serves exclusively for the escape of water, some of it hot, from the springs met with in the tunnel. The absence of any mention of this in the Paper is due to its having occurred since the Paper was prepared; there has been no omission on the part of Mr. Fox.”

He could only congratulate Mr. Fox and the Institution on the expression of satisfaction which his account of this great enterprise had called forth from the Direction of the Swiss Federal Railways. The Paper raised a number of really difficult points in tunnelling, such as ventilation, dealing with soft rock and enormous quantities



The President. of water, and the best methods of boring, all of which lent themselves to interesting and valuable discussion.

The Author. The AUTHOR mentioned that he had received from the Italian Ambassador and the Swiss Minister in London, expressions of their regret at being unable to attend the discussion. He was sorry, too, that neither Dr. Locher-Freuler, Dr. Brandau, nor Dr. Sulzer-Zeigler could be present, the distance, the time of year, and their numerous engagements preventing them from crossing to England. With regard to the letter from which the President had read extracts, he desired to take this opportunity of asserting, as he had explained in the newspapers, that the statements which were made about the heat and the danger of the tunnel were false; indeed, they were ridiculous. They had led to the erroneous impression that it was necessary to close the windows of the train when passing through the tunnel, whereas the air was perfectly fresh and not unpleasantly warm; and these absurd rumours had even gone so far that it had been reported that the trains were enveloped in blankets on account of the heat! All such incorrect allegations emanated from people who for some reason were antagonistic to the tunnel. One point which he had not referred to in the Paper, but which he now mentioned as it might arise in the discussion, was that the speed of the drilling had been raised to such a point that any further increase was hardly necessary. Where further improvement was now wanted was in the removal of the debris from the face, because that was what occupied the time. Several methods had been tried. In one case, at the moment of explosion, jets of water under a pressure of about 90 atmospheres were directed upon the rock while it was in the act of being removed by the explosion; the water forced the rock back and distributed it over 100 feet of driftway instead of its being piled up in a huge mound in front of the actual explosion. By that means forty men could be put on to pick up the rock instead of the six men who would be working at the actual face. Any engineer who wished to make a fortune in the future had only to hit on some method of getting rid of rock quickly from the face. In the Library he had placed some photographic views which he hoped the members would look at, as the stereoscopic effect gave a vivid representation of the phenomena of tunnel-construction without any of the danger, inconvenience, heat, or fatigue inseparable from the actual work. When the Paper was written, the arrangements of the electric traction had not been finally settled, and that matter had therefore been omitted from the description; but the Federal Railways had put into his hands some books upon the subject, and he would mention briefly the salient points. The

work had been carried out by Messrs. Brown, Boveri & Co., of The Author. Baden, in Switzerland. The three-phase system was used, the current being generated and supplied to the motors at a pressure of 3,300 volts, with a periodicity of 16 cycles per second. The locomotive was of the bogie type with five axles, of which three were motor-driven, without gearing. The weight on the driving-wheels was 42 tons, and the length of the vehicle was 40 feet 6 inches. The normal power developed was 900 HP., the maximum being 2,300 HP. The copper conductors were placed overhead, fixed to the arching of the tunnel in order to offer no obstruction to the platelayers maintaining the permanent way. They were fixed in duplicate, so that in the event of breakage of one the traffic was not interrupted while the repairs were being effected. At 42 miles per hour the normal drawbar-pull was 7,700 lbs. and the maximum 20,000 lbs.; and at that speed passengers were now taken regularly through the tunnel in 18 minutes. To give some idea of the advantage of the tunnel to travellers he might mention that passengers leaving Victoria Station, London, at 11 o'clock in the morning could, on three days of the week, travel through from Calais to Milan without change of carriage in 25½ hours, and the only route by which this could be done was that of the Simplon tunnel. On the table were several samples of the rock which would well repay examination, and also a specimen of the lamp used by the miners, which burned olive oil. The lamp could be hung in a variety of ways, and wherever it was suspended it would remain in the right position. He thought that form of lamp might be adopted in England with advantage. The Author then exhibited a series of lantern-slides showing the tunnel in course of construction, the boring-machines and their method of use, the systems of ventilation and water-spraying, etc.

Mr. F. HUDLESTON had been unable to make out from the Paper Mr. Hudleston. whether the haulage had been done by steam-locomotives or not, and if the Author could tell him that it might affect the remarks he wished to make on the subject of the ventilation of the tunnel during construction.

The AUTHOR replied that the haulage had been done by steam- The Author. locomotives which fired up outside the tunnel; they travelled up to within 2 kilometres of the working-face with their fires damped. From this point the traffic was worked by compressed-air locomotives.

Mr. HUDLESTON remarked that 210,000 cubic feet of air per minute Mr. Hudleston. was a very large quantity. With steam-locomotives, even when the fires were damped, there was generally a good deal of steam, and much trouble was caused in a long tunnel. The tunnels with which he had been connected were chiefly "tubes," which, he was sorry to

Mr. Hudleston. see, the Author said were during construction the worst ventilated of all tunnels. A tube was not an easy thing to ventilate while it was under construction, for there was not much room in it. But there were not more than about a dozen men at the face of a tube, and as a rule in London there was no contamination of the air of the tube with the steam from the haulage-engine. Practically what had to be dealt with was the foulness due to the men themselves. No doubt it was better for the men to have fresh air, but the ordinary navy did not care much about it, and on the few occasions when ventilation to some extent had been tried, the men had generally objected to the draught. As a rule, the ventilation effected by the amount of air given off by the air-driven pumps at the face—pumps which were now almost universally used—was sufficient to cool the face. He admitted that a person who was not used to such conditions generally felt the effect of the bad air, but when a navy had got used to it he did not mind it much. If a steam-locomotive were put into a tube it was necessary to be very careful, and it might be interesting to mention an occurrence during the construction of the Central London Railway, when for a time steam-locomotives were in use. The tunnel had been driven, the railway was practically completed from end to end as far as the lining went, and it became necessary to lay the permanent way and finish the stations. The tube was constructed under high pressure; he believed no other tube railway of that magnitude had been completed in less time. When the permanent way had been partly laid, it became necessary to use light engines for the haulage of the material, and soon the workmen in the tunnel were affected by the foulness due to both the gases from the coal and the steam. A good deal of trouble was caused, and a method of ventilation was then adopted such as was generally carried out in colliery practice. At every other station a 5-foot Blackman fan was put up, and in one case, where there was an awkward arrangement of intakes, a 6-foot fan. All the passages were blocked at the uptake shafts, except where the fan ran, and doors were made through these bulkheads. The intermediate station-shafts were downcasts, and the fans sucked up all they could. By these means the tunnel had been kept practically free from fumes and steam in spite of the engines running. Trouble had occurred occasionally with the heavier engines afterwards, but still, things had gone on fairly well under steam. He had found that the quantity of air pumped out of the tunnel was about the same as the Author said was pumped out of the Simplon tunnel. The fans were driven by electric motors of about 10 HP., though as a matter of fact they did not need more than 5 HP., and the nominal delivery

of all six fans was about 285,000 cubic feet per minute. He Mr. Hudleston. did not suppose that delivery had been obtained, because the passages were constricted; but it was a very large amount, and the tunnel was ventilated fairly well. The draught was not appreciable because there were in reality six separate installations. One thing about the Simplon tunnel that struck him was that an enormous amount of air had to be taken through a single heading, which, according to one of the illustrations of the Paper, was about 70 square feet, though he thought the Author had said it was about 60 feet. If it were 60 square feet the velocity of the air would be about 60 feet per second through that small heading, and if it was the larger size, $7\frac{1}{2}$ feet by 11 feet, which one of the illustrations of the Paper scaled, the velocity of the air would be 40 feet per second. No man could work in that hurricane with comfort. Although most of the work would be done in the break-ups, where the area was much larger and the velocity less, still it did seem a very large amount of air to pass through. Of course, if the 210,000 cubic feet was the total supply to both ends of the tunnel, these velocities would be approximately halved, but even then were extremely high. At the face they did not get the full quantity. The very ingenious arrangement whereby a current was induced up to the face gave a good deal of air, but how much he did not know: he supposed it could easily have been measured, but it could have been nothing like 210,000 cubic feet per minute, for no man working hard and perspiring freely could stand a gale of that sort; he would quickly be in the doctor's hands. The changing of clothing, etc., on the part of the men was of course practically a necessity in a long tunnel. The same precautions were taken in England in all compressed-air tunnels, where they were more necessary than in a free-air tunnel like the Simplon. In compressed air men perspired much more profusely than in the open air, and became practically drenched, and in the Simplon and other Alpine tunnels he supposed the men working at the face were in much the same condition; but the worker in compressed air had to face the chilling effect of the air-lock when leaving his work. Some attention was paid to those matters in England, but it was not possible to treat the men in the same fatherly way they were treated in Italy and elsewhere, for the ordinary English navy did not care to be nursed. The Paper stated that for every foot of air blown into the St. Gothard tunnel, 25 feet were supplied to the workmen in the Simplon. In the Arlberg tunnel the supply was said to have been about 8,000 feet per minute, but he did not think any very special ventilating-arrangements were provided there. The temperatures mentioned in the Paper were

Mr. Hudleston. extraordinary, and were never met with in ordinary tunnelling. In tube work the temperature seldom rose much above 75° F.: in compressed air it might reach 80°, but hardly beyond that. It was only in compressed air that the higher temperature was reached, generally at the top of the working-face, where, owing to the extraordinary quantity of heat given out by the grouting lime put in at the back of the iron lining, the iron was often too hot to put the hand upon. In the lower parts of the tunnel that temperature was seldom reached; even 80° was quite high enough, and necessitated special precautions in cooling down. It would be interesting to know how long the men had worked in such temperatures as 129° to 134° F., and whether they had found it very trying; also approximately how much air per man had reached the face. He would be glad if the Author could state also the total number of men working in the tunnel, because that would give an idea of what air-supply the 210,000 cubic feet represented.

Mr. Hodson. Mr. C. W. Hodson thought it would be agreed that the Paper was a very interesting account of a piece of work of unprecedented difficulty, and that the wonderful manner in which the difficulties had been met and finally overcome was worthy of the highest praise. Some of those difficulties were very like those experienced in 1890, during the driving of the Khojak tunnel, on the railway from Quetta towards Kandahar, which, though only about 2½ miles long, or about one-fifth the length of the Simplon tunnel, was still a very notable work. There, however, there were no hot springs. Like the Simplon, the Khojak tunnel was laid out with gradients ascending from each end to the middle, where it was intended that the headings should meet, and, as at the Simplon, the headings did not meet at the middle after all. One was unduly delayed, and the other had to be driven for a considerable distance down-hill, in spite of great difficulties, due to the large amount of water in the heading. The rather peculiar position of that tunnel had made it necessary for the western mouth to be about 150 feet lower than the eastern mouth, and as a consequence the gradient on the eastern side was only 1 in 1,000, while that on the western side was the rather heavy one of 1 in 40. The western heading was driven at the rate of about 60 feet per week until it had passed the summit and was on the downward gradient, where it struck very heavy springs of water. The western heading at that time was about 500 feet away, and was itself in great difficulties owing to rotten ground and torrents of water, against which the men could hardly stand up, though here the gradient helped a great deal, as it enabled the water to get away quickly. Time being the main consideration, the engineers decided to go on with the eastern heading

in spite of difficulties. They adopted the same expedient as that Mr. Hodson. used in the Simplon, driving the heading upwards at intervals until it was 15 feet above its proper level; but finally they had, owing to the water, to retire and to build a wall across the heading. In the west heading also an expedient very similar to that described in the Paper was adopted; a side heading was driven from a point about 100 feet back from the face so as to try to get behind the springs of water, and to relieve the pressure to a certain extent. When the west heading was approaching the drowned heading it was driven up to the level of the other, instead of adhering to the gradient of the tunnel; and the engineers kept a long drill-hole ahead until they struck the eastern heading, which was drowned, and allowed the water to drain away gradually, thereby avoiding the great rush of water, which would have been attended with some risk.¹

Mr. MAURICE FITZMAURICE observed that everyone connected with tunnelling in rock knew that the removal of debris from the face of the heading was a most important matter, as it took up practically half the time. The Tables at the end of the Paper—one of which he understood related to the time when the work was going on very favourably, and the other to the time when it was being carried on under great difficulties—showed that the time spent in drilling and the time spent in getting rid of the debris were about equal. When the work was proceeding quickly, drilling occupied $11\frac{1}{2}$ hours, and getting rid of the debris $12\frac{1}{2}$ hours, in the 24; when the work was going on under difficulties, the drilling took $13\frac{3}{4}$ hours, and getting rid of the debris $10\frac{1}{2}$ hours. He had dealt with this question rather fully some years ago, when a Paper on the Topley tunnel² was read before the Institution. It was pointed out in that Paper that the improvements in drills and explosives had been so great that the only chance of getting any further increase in the rate of progress in the headings would be by devising some method for dealing quickly with the debris at the face. The Author of the present Paper had suggested that that matter might well be studied by engineers, but as the Author had been exploring the field for a long time under very favourable circumstances, Mr. Fitzmaurice was quite sure he would be able to give some further information as to what had been tried in connection with the important matter of removing debris at the Simplon tunnel. It would be of great interest

Mr. Maurice
Fitzmaurice.

¹ G. P. Rose, "Report on the Chaman Extension Railway." Technical Papers of the Government of India, No. 35. (In the Library of the Institution.)

² P. Rickard, "Tunnels on the Dore and Chinley Railway." Minutes of Proceedings Inst. C.E., vol. cxvi, p. 159.

Mr. Maurice
Fitzmaurice.

if he would state whether any experiments had been made, and whether any improvement in the speed had been achieved as the work went on. It was not very encouraging to those who had to deal with that class of work not to know what had been done before. Mr. Fitzmaurice had looked back to the Paper written by the Author's son in the earlier stages of the work, and the only method of dealing specially with the matter which he could see mentioned there was the adoption of a steel plate which was put down on the floor of the heading, so that the shovelling up of the debris might be more expeditious. Of course, it was not a question of getting rid of all the debris; the important thing was to get rid of the portion in the middle of the floor of the heading, so that the drilling-machines could be brought up to the face again. In that connection he noticed that the heading was a particularly wide one in relation to the height, and he would like to know whether it had been purposely made so with the object of getting the debris quickly to the sides of the heading so as to give room for the drilling-machines to be brought up to the face as quickly as possible. He noticed that the length of the holes drilled was very short; they appeared to average 1.2 metre, say 3 feet 6 inches to 4 feet. He did not quite know why such short holes had been adopted. Short holes meant more attacks on the face during the 24 hours, and consequently a larger number of times when the drilling-machines had to be taken away from the face and brought back again. At first sight that would appear to be rather a waste of time, but he was quite sure there was some good reason for what had been done. In Table I there were nine attacks on the face during the 24 hours when the work was going on quickly, and in Table II five attacks when the work was going on slowly. Consequently, considerable time must have been occupied in taking away the machines and bringing them back again. Under those conditions it did not seem to be of such vital importance for the men to relieve each other at the machines without a moment's pause. With the machines being so often brought back from the face, the gangs might frequently have relieved each other during the time when the machine was not at the face, which would have saved the men's time. He also noticed that a very large quantity of explosives had been used per cubic yard of rock, and he desired to know whether that had been done with a view to greater shattering of the rock so as to render removal of debris easier, or on account of the particular class of rock met with. With regard to the rate of progress, the rapidity attained had not been reached in any other tunnel that he was aware of. In the Totley tunnel the progress on some occasions had very nearly reached the average rate for the Simplon tunnel, but

the average all through the work had never been anything like what had been attained at the Simplon. On the other hand, the heading adopted at the Totley tunnel was nearly double the size of the heading in the Simplon, the latter being 55 square feet, whereas the Totley heading was 10 feet by 10 feet. In the case of the Totley tunnel the large heading had been adopted in order to enable larger trucks to be brought in to deal with the rock. If the Author could give a little further information on the points Mr. Fitzmaurice had mentioned, it would add still further to the high value of the Paper.

Mr. Maurice Fitzmaurice.

Mr. ERNEST BENEDICT wished to know what had been the hygro-metric condition of the air in the tunnel. It was absolutely impossible for Europeans to do hard manual labour in a temperature of 80° F. in Bombay or Calcutta, whereas in a dry atmosphere, as in Egypt or the Punjab, that temperature did not prevent work from being carried on. Personally, although he had had some experience in India, he had never known any large body of Europeans working for any length of time in such temperatures as those mentioned by the Author, though there were records of English soldiers having done wonderful feats in great heat during the Mutiny. He would also like to have some information as to the sanitary arrangements, which appeared to have been perfect, as he understood that the miners' illness was due entirely to neglect to promptly get rid of the dejecta of the workmen. With reference to the levels, it seemed extraordinary to a man who had had to do a little tunnelling work, that under the circumstances such accuracy should have been attained. The curvature of the earth must have made it very difficult to get a sight through: the Author said that he had got a sight of 5 miles, but that must have been almost accidental. The Author also said that an error of about 3 feet was anticipated in the length; probably that was arrived at by halving an extreme difference of 6 feet in the observations. It was an extraordinary result considering the difficulties of working in such huge mountain masses. It would seem almost impossible, under the circumstances, to get within a few inches of the level, as had been done. It had often seemed to him that in such cases a rough but easy check might be put on the levels by means of water, though of course in long tubes time would have to be allowed for the water to get to the level.

Mr. Benedict.

Mr. OSCAR GUTTMANN recollected seeing, 32 years ago, Mr. Brandt's first drill. He remembered, too, the excellent impression Mr. Brandt had made upon everybody as an engineer and a gentleman, and he would have been glad to see, in the Paper, some stronger recognition of Mr. Brandt's work. Mr. Brandt's rock-drill had probably done more than anything else for the progress of modern tunnelling.

Mr. Guttman.

Mr. Guttman. In conjunction with high explosives it had undoubtedly made progress in that kind of work extremely easy. The work of the first Brandt drill on the Sonnstein tunnel in Austria was undoubtedly much slower than anything at the Simplon, and it would be interesting to have a comparison of the rate of progress made in the various tunnels from the Sonnstein tunnel down to the Simplon. The consumption of explosives was not given in the Paper per cubic yard of rock, but calculation showed that 2·84 lbs. of dynamite was used per cubic yard of rock. That was about 25 per cent. less than at the St. Gothard, where, he believed, the same kind of rock was met with. As it was very important for engineers who had to undertake tunnelling work to know exactly what they could get from the explosives used, he thought a little supplementary information would be much appreciated. He had been very interested in seeing the familiar miner's lamp, a lamp which his own antiquarian researches had shown him existed 500 or 600 years ago in Hungarian and German mines, and which no Italian miner would be without. From the remarks of the Author it would seem that he thought the lamp was unknown in England, but Mr. Guttman believed he had seen it—or a very similar lamp—in Cornish mines. He did not think anything simpler or better calculated to withstand rough usage could be invented, and he fully endorsed what the Author had said as to the ease with which the lamp was manipulated; it would stick almost anywhere. The nozzle used for producing spray was different from any he had yet seen, although it was like some others in having inside a spiral which caused a jet of water to revolve and come out in fine spray. Nozzles were largely used for producing a fine spray of water in sulphuric-acid chambers; such nozzles were smaller than those used at the Simplon tunnel, and the spray produced was so fine as to be really a fine mist. The disease of anchylostomiasis, caused by the presence of a small worm, the *Anchylostoma duodenale*, in the intestines, had been met with in the St. Gothard and many other tunnels, and was first studied in the lead and silver mines of Příbram in Austria by a medical man, Dr. H. Goldmann. A Paper¹ on the subject had appeared in the Journal of the Austrian Society of Engineers and Architects, and it would be found in the library of the Institution with an enlarged picture of the worm. That was long before so-called miners' phthisis in this country troubled the minds of officials.

¹ L. Jehle, "Die Anchylostomiasis, eine Berufskrankheit der Tunnelarbeiter." Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, vol. liv (1902), p. 542.

Mr. BERTRAM BLOUNT mentioned that the analysis given on p. 76 Mr. Blount. had been made by his assistant, Mr. Levy, in his laboratory. Its interest lay in the entire absence of chlorine, and in that respect it was water of a kind new to all chemists and water-engineers. He did not suppose that a case of that kind had ever been met with before, and the conclusion was irresistible that the water had never been on the surface of the globe—that it was, as the Author said, plutonic. To explain how such plutonic water could occur, and why it should be brought to the surface of the earth at that very moderate depth, was a matter for the geologists, and he understood they were somewhat exercised about it. It might be useful if an opinion upon that point could be elicited from geologists.

Mr. WM. R. GALBRAITH, Vice-President, remarked that the Paper Mr. Galbraith. described a great work, admirably planned and carried through with the utmost perseverance, and it might be that the members were a little reluctant to discuss trivial matters in connection with so elaborate an undertaking. Long as the Simplon tunnel was, probably a greater aggregate length of "tube" tunnelling had been carried out in London in the last few years, and there also he had been astonished at the accuracy of driving. Of course, there was no single tube 12 miles in length; but in the Simplon tunnel the alignment was straight, and this, with the use of very powerful and fine instruments, had made for accuracy. In constructing the Baker Street and Waterloo Railway, it had been impossible to work on straight lines. For instance, lines were laid down in the shaft in the River Thames, and from there the tunnel was driven towards Piccadilly. There was no straight drive from the Piccadilly shaft, because the tunnel had first to be driven across into the Haymarket and also round a curve at the bottom of the Haymarket; and yet, with all that, there was not an error of more than $\frac{1}{2}$ inch in the lines when they met. In the levels there was really no error at all in some cases: it was a fluke, of course, but it came out all right. He was also astonished at the rate of progress of the work in the Simplon tunnel—about 17 feet per day at each heading. He thought that for tube-tunnelling a record had been established on some of the works that had been carried out lately. On the Charing Cross, Euston and Hampstead line, 22 feet of tunnel per day had been completed. Mr. Price, the contractor, had used his rotary digger, and the lines had been driven very accurately on the whole. He believed Mr. Ross had established a further record on the line to the Strand. The difficulty of driving 17 feet per day in a tunnel of the length of the Simplon tunnel made that great work wonderful. There was not such good ventilation in some of the tunnels in London, because such scientific and careful

Mr. Galbraith. arrangements were not made for the work. For instance, one of the contractors did not use electric engines to draw the spoil from the face to the shaft; he used ponies, and when Mr. Galbraith ventured to tell him that that method was quite out of date he was somewhat offended. The work was done quickly, however. The idea of granite arches 5 feet thick made an engineer's blood run cold; but the Author did not say how much there was of such work, or what the general lining of the tunnel was. No doubt arches, particularly arches of such dimensions, had been used only in very exceptional situations. Government inspectors required that all tunnels should be lined, because with an unlined tunnel there was likelihood of the fall of rock. With regard to the speed of tunnelling, for the old-fashioned method of driving tunnels in ordinary ground the rule of thumb, "a length per face per fortnight," meant about two lengths of 12 or 13 feet per month at a face, or 24 feet per month. When that was compared with 17 feet per day the latter could only be said to be marvellous.

Mr. Colson. Mr. C. H. COLSON asked whether the Author could add to the Paper a plan and a few more details showing the setting-out. A plan showing the lines of triangulation had been exhibited on the screen, but there was nothing in the Paper. He himself had never had to do with large tunnels, and he would very much like to know the basis on which arches 5 feet thick had been worked out: on what grounds had their thickness been decided?

Sir Douglas
Fox.

Sir DOUGLAS FOX, Past-President, desired to confirm what Mr. Galbraith had said as to the great accuracy with which the assistants of tunnel-engineers had been able to set out tunnels under difficult circumstances. In the case of the Mersey tunnel¹ the difficulties were very considerable, because, as in London, it was impossible to place the shafts on the line of the tunnel, and there were curved headings leading from one of the shafts to the tunnel, consequently the setting-out was complicated. It was rendered still more difficult by the fact that the lines were set out in a drainage-heading which was a continuous shower-bath. It was exceedingly difficult even to walk along the heading, and still harder to perform any delicate operation in it. In that case, when the two headings were about to meet it was decided that the Mayors of the two towns should come and shake hands in the middle. He ventured to suggest to the resident engineer that a bore-hole should be put in before the Mayors came, at which he was offended, saying that it was unnecessary, as he was quite certain where he was.

¹ See Minutes of Proceedings Inst. C.E., vol. clxii, p. 344.

However, Sir James Brunlees and himself insisted upon having it, with the result that a bore-hole was put through from one side in the centre-line, and the edge of the bore-hole struck the centre-line on the other side. On the Charing Cross, Euston and Hampstead Railway, with which Mr. Galbraith and his own firm were connected, there were six closures, and five of them had come within $\frac{1}{4}$ inch. In the sixth case the resident engineer telegraphed to say he was very sorry to have to report that the difference was $\frac{1}{2}$ inch, and he could not account for it! That showed extreme care on the part of the resident engineers and great credit was due to them. There was quite as much difficulty in dealing with such matters, which were complicated by the traffic in the streets overhead, by the curves in the streets, and by the want of anything like a really good base for the work, as there was in longer tunnels. The Author had said very little about his own part in the matter, and, being his brother, Sir Douglas did not wish to say much about it either, but he would like to emphasize the fact that if there had been good ventilation-arrangements they had been the outcome of exertion on the part of the Author to have proper conditions inserted in the specification. He only wished it were possible to get similar clauses into some English contracts. It did not matter to him as an elderly man, but for the sake of some of the younger engineers it would be very desirable, because very often the air at the face of tunnel-works in England was very trying, not merely to the workmen, who did not seem to mind it, but to the engineers, who did. When the result attained in the Simplon case was considered, he thought the Commissioners who laid down the rules on which the work had to be carried out had every reason to congratulate themselves. The contrast between the St. Gothard tunnel, with its sad history, and the Simplon tunnel, with its empty hospital, spoke volumes for what could be done by care; and he thought engineers ought as far as possible to insist that the working man to whom they owed so much should in all large undertakings be looked after, even if he would not look after himself, and should be protected, even against his will.

Mr. WALTER HUNTER mentioned that about 4 years ago he visited the Simplon tunnel, and was greatly struck with the care taken for the comfort and health of the men employed there. The machinery outside was very interesting, and had he known he was going to be detained in the country, he would have asked for a letter of introduction in order to examine the work thoroughly. As it was, he went into the tunnel as far as the casual visitor was allowed to go, and what he saw of the arrangements for the health and

Sir Douglas
Fox.

Mr. Hunter. comfort of the men made him wish that they could be provided for the workers at home. No doubt the tunnel would be an important means of communication between the two countries which it joined, but he strongly advised people after going through the tunnel in one direction to come back over the pass, for, probably, a finer piece of scenery could not be found anywhere in the world.

Mr. Coath. Mr. D. D. COATH had visited the Simplon tunnel shortly after the galleries were pierced, and he could only say it was a very remarkable piece of work. The whole construction of the tunnel had been a question of ventilation, because without efficient ventilation the tunnel would never have been completed. From the temperatures which he had heard of before he went into the tunnel, he expected to find something very terrible. The temperature certainly was as reported, but there was no great discomfort, simply on account of the excellent ventilation which existed. In fact, during the 4 hours he was there he was much more comfortable than he had been on the underground railway in London before it was electrified. The arrangements for the men had been about as perfect as they could be. As one speaker had observed, they probably would not do in England, because the British navy might object to being nursed; but the Simplon workmen had certainly been nursed to their own benefit. One advantage the Simplon tunnel had over the other two Alpine tunnels was the ease of access. An ordinary engine took the train from Lausanne to Brigue. That was very different from the St. Gothard line, where two or three engines were used, and the trains twisted about for hours on all sorts of curves and through spiral tunnels before getting to the tunnel itself—a fine work from a purely engineering point of view, but very slow and expensive to work. A curious coincidence about the Simplon tunnel was that it was finished and opened just 100 years after the Simplon road, which was regarded as the greatest work Napoleon ever constructed. That was a work undertaken solely in the interests of war and destruction, while the Simplon tunnel had been constructed wholly in the interests of peace and civilization.

The Author. The AUTHOR, in reply to Mr. Hudleston's questions, pointed out that No. 1 tunnel had been kept about 1 kilometre behind the excavation, and had been arched quickly, as shown in *Fig. 11*, so that there was a full area of about 250 square feet along which the current passed, and it was in that the men travelled. The air was blown in along No. 2 gallery, and at every 200 metres (656 feet) there was a transverse gallery with doors. The current of air naturally took the shortest route, and went through the last cross cut which was open, returning by the larger section, where the velocity was low. The

men worked in the advance gallery, where only a comparatively small volume was required, amounting probably to about 2,000 cubic feet per minute. The speed of the current was not by any means excessive where work was proceeding, and by keeping open the doors in the different galleries it was possible to regulate the current to any point desired. The 210,000 cubic feet per minute mentioned in the Paper was the total supply of air to both ends of the tunnel. Mr. Hudleston had also spoken about the nursing of the English navy. It might be quite true that he did not want it, but in most jobs he certainly did not get it. With some noble exceptions, the English navy was not properly considered, and the question of ventilation of tunnels for his welfare was not sufficiently attended to. When future tunnels were driven in England, he trusted the question of ventilation would be given a much more prominent place. It was difficult to give the number of men that had worked in the tunnel, because it had varied; but he thought it might be taken that with the works in full operation the total number of men had been rather more than 3,000, that was, 1,500 to 1,600 on each side. Of that number probably one-third had been out in the open air or in the workshops, and the other two-thirds had been either in the advance heading, or engaged in enlarging the gallery into the tunnel, or on the arching. The trains used to go in three times a day, at 6 a.m., 2 p.m. and 10 p.m., with about 200 to 300 men each, who were dropped at different points in the tunnel for the carrying on of the work. With regard to Mr. Fitzmaurice's question as to what had been done in the matter of clearing away the debris, in his son's Paper some description was given of that, but he only hinted at the question of *marinage*. One method was to lay plates on the floor, so that when the explosion took place there was a smooth surface for the rock to slide over, and it travelled some distance along the heading: the men shovelling up the debris thus had something smooth for their shovels to work upon. The question of *marinage* had not yet been solved, although a good many experiments had been made. In one of these a high-pressure pipe was taken up as near to the face as was safe; it was then covered with old timber, sleepers, etc., and jets of water were fixed near the end of the gallery, with the jet blowing away from the face, so that the moment the explosion took place the water could be turned on and directed upon the flying rock, forcing it away from the face and distributing it many metres along the passage, instead of its being heaped up in a mound in front. That was a subject well worthy of consideration and further development. The heading had been made 10 feet wide in order that three drills might be at work at a time,

The Author. and it also gave two narrow roads, an up and a down, for the wagons. With regard to changing the shifts, he need hardly point out to Mr. Fitzmaurice that to arrange for that to take place when the machines were withdrawn into the cross galleries out of the way of the explosion would have been impracticable, because it was never known at what hour the blast was going to be made; it depended entirely upon the speed of the drills. Mr. Benedict had asked about the sanitary arrangements, and how the excreta had been removed. There had been a custodian to each latrine, whose business it had been to keep everything sweet and clean. The Author had never been able to discern, when in the tunnel, the proximity of the latrines. With regard to the calculation of possible error, a volume had been written by Dr. Rosenmund on the matter, and it was to him and his assistants that the wonderful accuracy of the line was due. Mr. Guttmann had asked for something more to be said about Mr. Brandt. The Author had not said much in the Paper because he had often said it before, but he could assure Mr. Guttmann that it was not from want of regard or respect for that good man's memory. The way in which Mr. Brandt had carried out his work, and the many improvements he had introduced from his experience at the St. Gothard, were beyond all praise. He had endeavoured to do justice to all the gentlemen in charge of the work. Messrs. Brandau, Sulzer, and Locher were three men—had Mr. Brandt lived there would have been four—who formed a wonderful combination of dogged determination, of financial and mechanical skill, and of a frame of mind that would absolutely refuse to acknowledge defeat. Over and over again it had been said the tunnel was impossible and could not be made, and Dr. Sulzer had replied, "'Impossible' is not in my dictionary; the tunnel must go through." The credit of that was due to the gentlemen, German, Swiss, Austrian, and Hungarian, who had carried out that wonderful work. Mr. Blount had asked a question which the Author was afraid he could not answer, about the definition of plutonic water. He had had a very interesting letter from Dr. Locher, who said he believed that the real explanation of the peculiar phenomenon encountered in the tunnel, namely, two springs of water within a metre of one another differing by many degrees in temperature, was that one of them was plutonic water from below, water that had never seen daylight, and the other was surface water, heated by the rock and containing chlorine. With reference to the accuracy of lines and levels, Mr. Galbraith had given some very remarkable examples, and the Author desired to supplement them with some account of work in the tube railways of London, in which Sir Douglas Fox and he had had the pleasure of being associated with Mr.

Galbraith and the late Mr. Greathead. When he said that there had been numerous cases in which two shields had been put down two shafts 1,000 or 1,200 yards apart—shafts which were off the centre-line—that a drift had been made from the shaft to the centre-line in the middle of the road, that the line was on curves and gradients, and that notwithstanding all this those two shields had met edge to edge and had actually been left in as portions of the lining of the tunnel, it would be seen how high a degree of accuracy had been attained. As to the progress, 17 feet per day had been the average. There had been days on which as much as 32 feet had been driven through granite, which was quite a record. The arching 5 feet 6 inches thick had been used only in those difficult places where the timbers had been crushed. The average thickness of the lining from end to end might not exceed 2 feet 3 inches or 2 feet 6 inches. In many places, of course, an invert had to be provided to allow for the side pressure. In conclusion, he thanked the members for the attention they had given to the Paper, and he trusted it might be a useful record in the Proceedings of the Institution. The Author.

Correspondence.

Dr. KARL BRANDAU expressed his pleasure at the excellent grasp of the subject displayed by the Author. Whilst those responsible were contending, in the heart of the mountain, with difficulties which they had been able to conquer only by severe and protracted toil, they much dreaded the criticism of engineering experts. This fear had fortunately proved to be unfounded, and on all sides they had met with unprejudiced and hearty approval. This was shown also by the friendly sentiments of the Author. With regard to deductions of scientific and practical importance made during the execution of the tunnel, besides the observations already recorded—concerning the distribution of the temperature at great depths below the surface, and with respect to the nature of the water encountered—knowledge had been increased by the observations made on the stratified construction of the Simplon range. Thus the transfer of great mountain masses from considerable distances was a new fact, as was also the penetration deep into the earth of distortions of the mountain strata. Below a depth of 6,500 feet were found beds of recent formations, underlying those of the



Dr. Brandau. Archaic period. Such beds of the Jurassic age, metamorphosed and greatly altered in their appearance, had formerly, in the absence of this knowledge, had to be included among the Archaic rocks, and thus the geological predictions respecting the Simplon tunnel had been to a large extent falsified. With respect to the effect of the pressure of the superincumbent mountain mass on the masonry of the tunnel, which was a very disquieting problem for the engineer, the opening up of these great depths had given no positive information. It had been affirmed by the highest authorities on this subject that the Simplon tunnel would be exposed to great rock-pressures. According to all theories very considerable pressures should prevail in all directions. It had also been assumed that the full intensity of the pressure would not come into play immediately on the excavation of the tunnel. It was thought it would be manifested only gradually, and would endanger the stability of the work if the thickness of the tunnel-lining was not calculated to resist such extreme pressures. Those who were responsible for the work had been bound to be guided by the practical experience gained in earlier tunnels—such, for instance, as the St. Gothard—in laying their plans. It had been impossible to obey theoretical requirements. During the construction, however, such evidences of general pressure had never been experienced. Where the superincumbent mass was greatest, the lightest type of masonry lining was almost universally employed, and it had never shown the least sign of damage. Wherever merely local and unimportant pressures had been observed, they were invariably due to decomposed rock of small internal cohesion. It could therefore be asserted that, according to the experience available to the present day, no considerable difficulties arose from the pressure of the superimposed rock in the construction of a tunnel, even at depths of more than 6,800 feet in good compact stone. On the other hand, it must not be forgotten that the constructional difficulties became enormously increased at such depths when the tunnel passed through more or less plastic materials of considerable thickness. Of this fact the history of the construction of the parts of the St. Gothard and Simplon tunnels where pressure was encountered yielded proof.

Mr. Colling-
ridge.

Mr. HARVEY COLLINGRIDGE ventured to think that the Author's strictures on the want of ventilation at the working-face of a tube railway were hardly deserved. Of three tube tunnels recently constructed, as well as the Blackwall tunnel, he could speak from experience as to the care taken by the engineers and contractors to ensure that a reasonable amount of air and efficient ventilation were provided. He had made numerous analyses, at the instance

of those responsible, in order to determine in what degree their efforts had been successful, and to discover whether at any places the fresh-air supply had been insufficient. On the compressed-air portions of the Euston extension of the City and South London Railway periodical examinations had been made at short intervals and he had been commissioned by the contractors to examine and report upon the conditions of ventilation in any confined parts of the workings and where the men were working in close quarters. The result of this had been that if any portions of the works were found not up to the standard deemed necessary, immediate steps were taken to remedy matters by exhausting the foul air and supplying fresh. With regard to this latter point, he would like to emphasize the fact that it was not sufficient to supply to the men in a tunnel a quantity of air which would give to each man the average of the number of cubic feet found necessary. The amount should be supplied to the men at the point where the carbonic acid was exhaled most freely, namely, the face and other parts where active work was going on. The quantity of impurities in the air at the working-face would usually be two to three times as much as in the body of the tunnel a little distance back, unless the air-delivery were kept close up to the shield. Other parts that particularly needed attention were the advance heading and break-ups, where ten to fifteen times the normal amount of carbonic acid in air might easily collect. The evidence of the senses could not be relied upon. On many occasions when the air felt extremely close and foul nothing to account for it could be detected by carbonic-acid determinations. When investigating the ventilation of a tunnel in towns by chemical methods it was important to pay due regard to the condition of the outside air which was being supplied to men below. In a dense fog he had found as much as 13·1 volumes of CO_2 per 10,000 volumes of air, or four times the normal quantity. If no regard were paid to this point, erroneous conclusions might easily be formed in such a case.

Dr. VON KAGER contributed the following notes on the tunnelling operations. As was well known, both galleries Nos. 1 and 2 of the Simplon tunnel were in the first instance driven by means of bottom headings about 6 square metres (65 square feet) in area. During the first few years of the working, following the usual practice, the bottom heading was first driven with a cross section of about 4 square metres (43 square feet), and the enlargement was then put in hand in lengths of about 50 metres. At each enlargement the heading was next extended to the full size, working backwards and forwards. All further excavation to attain the full section required was then carried out in the usual way. The ventilation of such a small heading was as a rule defec-

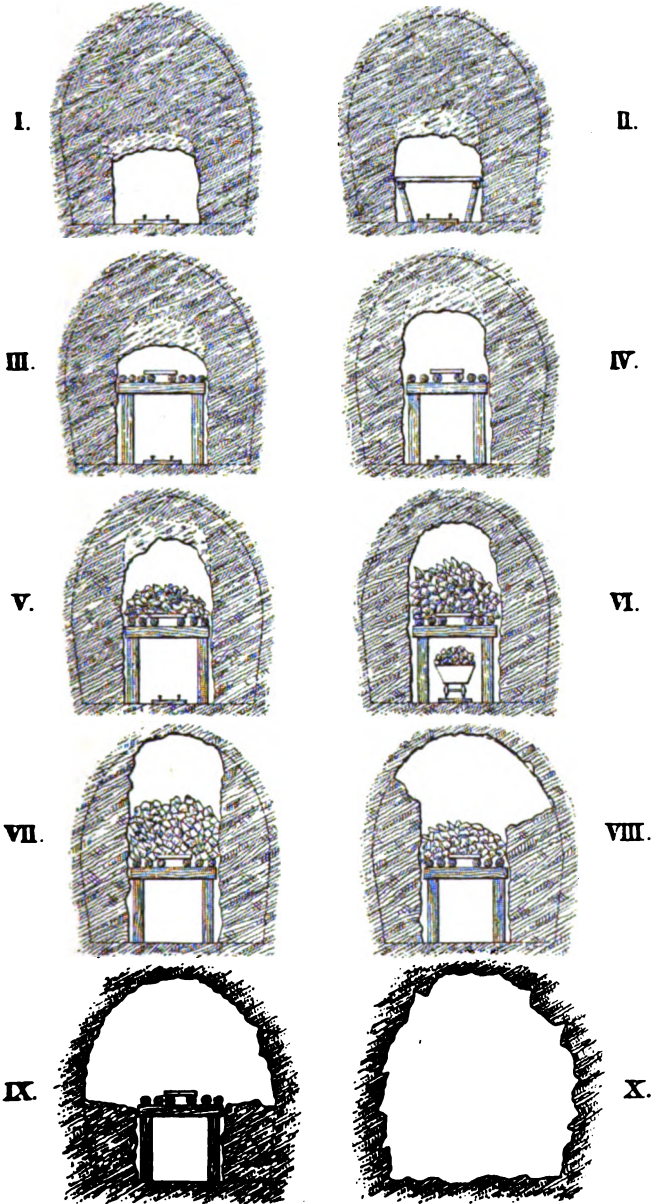
Mr. Colling-
ridge.

Dr. von Kager.

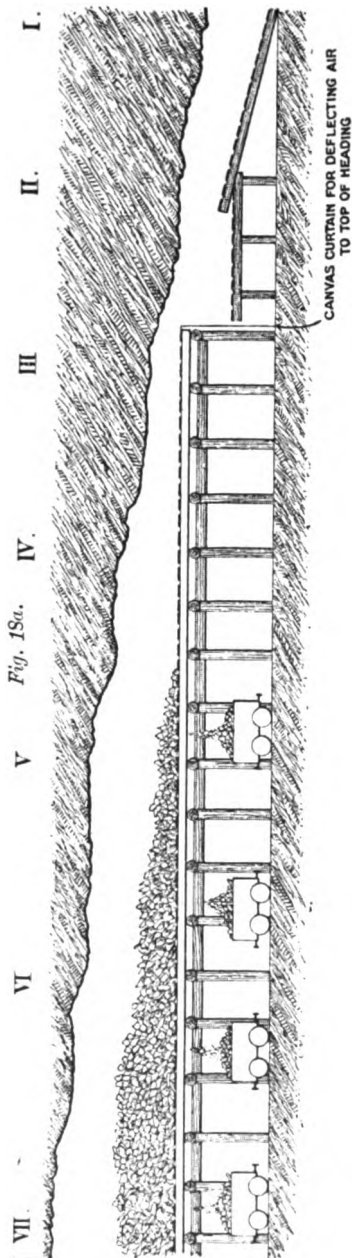
Dr. von Kager. tive, because the means provided for this purpose were only available for giving a good supply of air when the bottom heading was fully excavated. The slow progress in the heading first driven, as contrasted with that of the bottom heading (assuming that the staff and appliances were similar in both cases), might probably be explained solely by the indifferent supply of air, and the relatively greater interruptions due thereto after blasting. In addition to the foregoing usual drawback, there was in the case of the Simplon tunnel unbearable heat, which tended still further to diminish the capabilities of the workers. In order to overcome the increasing difficulties, the construction in this way of the upper headings was entirely abandoned (with the exception of a few places in unsound rock where it was necessary to open out on the old system). The construction of the headings was undertaken in the manner indicated by *Figs. 18 and 18a*. With the new system of working it became possible to afford an ample supply of cooled air to all the men engaged in the upper parts of the tunnel. With this improved aeration of the working-places, not only was the activity and working-capacity of the staff notably increased, but accidents were likewise sensibly diminished; for it was certain that the extraordinary freedom from accident experienced during the construction of the Simplon tunnel, as compared with other works of the kind, must be attributed mainly to the excellence of the ventilation. The reason of this was that, in consequence of the abundance of air supplied to the places where work was actually going on, the atmosphere was always clean and pure: each workman was able to convince himself that his situation was free from danger, and, on the other hand, was able to recognize any coming peril and to avoid it. Examination of the section of the tunnel showed that after the bottom heading was driven the principal mass to be excavated was situated up above it; it was therefore essential, while maintaining the working in the bottom heading, to clear away the masses of rock in the upper portion without notable diminution of the volume of the air-supply. The commencement of the excavation for the extended heading altered these conditions at once, and the whole of the main air-volume was needed for the upper section where numerous workmen were employed. In *Fig. 19* was shown the position in plan of the apparatus by means of which the exhaust air withdrawn from the last cross section of the heading was cleansed and cooled—the place at which the so-called separation of the moisture was effected, in order that the air might be conducted back into the working-places in as dry and cool a state as possible.

Figs. 18.

Dr. von Kager.



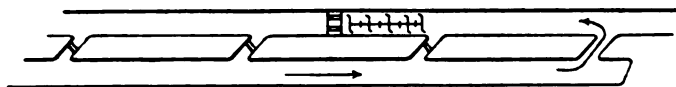
Dr. von Kager.



Within a short distance of the water-separation plant the first enlargement of the heading depicted in Section I was effected; the bottom heading was increased in height and continued as shown in Section II, until enough space was gained for the formation of a timber platform. This platform was constructed as soon as possible, partly as a protection against chance falls of loose blocks of stone and partly to serve as a working scaffold, which presented great advantages for charging the trucks from above. In Sections III-VII the further process of driving the extended heading was indicated. Until the full height of the heading was reached, no further removal of stone was required, but sufficient broken rock was permitted to accumulate on the platform to serve as a convenient standing-place for the miners. Any superfluous material could easily be permitted to fall into the trucks beneath, by the removal of a board at any spot required. From Sections VIII-X it would be evident that until the full size of the upper level of the tunnel was attained (with the exception of the small mass of rock on either side of the lower level) the debris did not need to be placed in the trucks, but could be allowed to drop into them direct, with the exercise of a little caution in dealing with the larger blocks, so as not to

cause injury to the rolling stock. As previously stated, this mode of driving was intended to provide means for the better use of the general ventilation: this was effected by the following plan. In the driving of the bottom heading (see Section III), when a section was complete, a brattice-cloth of coarse sacking was suspended over the opening so as not to interrupt the communication into the heading. By this system a powerful freshly-cooled current of air was passed through the upper portion of the workings, over the newly-broken hot rock. Not only did this plan

Fig. 19.



secure a better output from the miners, but a further advantage was gained, in that the weight of blasting-materials used was considerably reduced, and it was therefore advisable to adopt this mode of working wherever the formation of the rock rendered it practicable, even in much simpler cases of excavation; because the working-cost could be decreased to a degree not attained in any previous work of the kind. In the case of the Simplon tunnel, the excavation of the headings was divided into sections about 100 metres in length, and such a section was handed over to one gang, who executed the work in the manner described. As many as four to six of these sections were in operation at one time.

Mr. L. F. VERNON-HARCOURT remarked that, having been asked about 20 years ago, by Mr. James Forrest, the Secretary of the Institution at that time, to write a Paper on the Alpine tunnels, with special reference to the project of a tunnel through the Simplon, which was beginning to attract serious attention, he had carefully investigated the subject; and the results of his researches were eventually embodied in a comprehensive Paper ¹ dealing with the roads and approach-railways as well as the tunnels of the Alps. The Simplon route, first proposed in 1859, had been regarded for some time as a rival scheme to the St. Gothard route, till, by the help of German influence, the preference was given to the St. Gothard railway and tunnel, which offered a prospect of diverting the through traffic with the East from France to Germany; and it must be admitted that the St. Gothard line occupied a more central intermediate position between the Mont Cenis and Brenner railways

Mr. Vernon-Harcourt.

¹ "Alpine Engineering." Minutes of Proceedings Inst. C.E., vol. xcv (1889), p. 237.

Mr. Vernon-
Harcourt.

than the Simplon. The railway across the Simplon possessed the great advantages for a competing route of better approach-gradients, much shorter approach-railways, and a considerably lower summit-level than the three other main lines crossing the Alps, namely, the Mont Cenis, the St. Gothard, and the Brenner, and also than the less important Arlberg line; whilst, except in regard to the length of the approach-railways, the Simplon line was even superior in those respects to the Semmering railway crossing the comparatively low outlying Styrian Alps. These great merits for the accommodation of traffic had, however, been obtained only at the expense, as regarded construction, of a tunnel 12 miles 537 yards long, with a maximum depth below the surface of 7,005 feet, as compared with the St. Gothard tunnel 9 miles 527 yards long at a maximum depth of 5,733 feet, where great inconvenience was experienced in driving the tunnel from the great heat, attaining a maximum of between 87° and 93° , and inadequate ventilation. Owing to the greater heat anticipated in driving the Simplon tunnel at a much increased depth, the scheme for the tunnel, as approved in 1886, consisted in plan of two straight lines from each end, meeting at an angle in the centre, with the object of avoiding carrying it under the highest ridges, so as to diminish the maximum temperature to be encountered, which was estimated at 104° at the greatest depth of 6,895 feet. The tunnel, however, had been driven in a straight line, like the previous Alpine tunnels, with a consequent increase in depth below the surface; but the great excess of temperature of 33° above the original estimate, with only a moderate increase in depth due to the change of direction, must be mainly attributed to wholly unexpected hot springs which poured into the headings. It was evident, from the vivid description by the Author of the great difficulties encountered, that the work could not have been completed, in face of the almost unbearable heat, under ordinary arrangements; and that it was only by the provision of two galleries, and the very efficient ventilation thereby rendered possible, as well as the refrigerating spraying apparatus, that the driving of the headings had been at length brought to a successful termination. Other routes across the Alps had been formerly proposed;¹ but in view of the great obstacles which had to be overcome at the Simplon tunnel, and the great facilities it afforded for traffic, with its low summit-level and fairly easy approach-lines, it did not appear that another route could be made with good prospects of success, or indeed was at all required.

¹ Minutes of Proceedings Inst. C.E., vol. xcv, p. 271.

Dr. A. ZOLLINGER, of Berne, remarked that, whilst agreeing Dr. Zollinger. entirely with the Author in his opinion as to the arrangements for the tunnel-work, which had been carried out in a much more perfect manner than at the other Alpine tunnels, it would nevertheless have been possible to introduce improvements in the tunnel itself during construction by making more use of electricity and compressed air for the lighting and traffic. It was now recognized that it would have been preferable to adopt a greater available width at the level of the sleepers in the single-line tunnel; whilst the height of the tunnel in the centre-line was more than sufficient. Moreover, the distance apart of the centre-lines of the two tunnels should have been at least 20 metres (65 feet 8 inches), instead of 17 metres (55 feet 9 inches). The drainage-channel, also, in No. 1 tunnel had too small a section; and in the parallel gallery it should have followed the fore-head of the advanced heading as closely as possible. The system of constructing two tunnels offered a very great advantage for the construction of the first tunnel; but this advantage would have been still greater if the second tunnel had been constructed directly after the first. The question whether the construction of two tunnels was better effected with headings at the level of the sleepers or at the height of the arch had not been determined; but for the more extensive application of mechanical drilling, as for instance, for the entire excavation, the driving of the two advanced headings at the height of the arch was a great advantage. There had been two obstacles to the construction of the Simplon tunnel, namely, the large amount of cold water encountered, which, however, had been beneficial in lowering the temperature of the rock along a great length, and more especially the hot springs, attaining the temperature of the rock, which exceeded 40° C. (104° F.). This last circumstance could not have been foreseen without a complete knowledge of the geological strata, which proved to be somewhat different from what had been anticipated. The experience gained at the Simplon tunnel gave the following results. With a ventilating current of air of 40 cubic metres (1,413 cubic feet) per second, the temperature of the rock could be lowered from 50° C. (122° F.) to 30° C. (86° F.), or 20° C. (equivalent to 36° F.), provided no hot springs were met with. For refrigerating the air the same quantity of cold water must be employed as the volume of hot springs of 40° C. to 50° C. (104° F. to 122° F.) encountered, to cool down the air to 30° C. (86° F.). For preventing the heating of the water in the conduits, charcoal was an excellent non-conducting material, the increase in temperature being only 0.7° C. (1.26° F.) in a length of 1,000 metres (1,093 yards). The transmission of heat through the rocks, in kilogram-calories per metre per



Dr. Zollinger. hour, was 2·49 in the line of stratification, and 1·94 at right angles to the strata, through granite; 3·02 and 2·28 through gneiss and crystalline schists; and 3·26 and 2·10 respectively through limestone and black calcareous schists (or, in heat-units per foot per hour, 14·7 and 11·5 through granite, 17·8 and 13·5 through gneiss and crystalline schists, and 19·2 and 12·4 respectively through limestone and black calcareous schists). It was evident that the transmission of the heat did not vary much in these different rocks, and was less in a direction at right angles to the strata than along their plane. The transmission of the heat was not subject to great variations according as the rock was more compact and less stratified; but it appeared that the direction in which the rock was exposed to pressure had an influence on the transmission of heat.

15 January, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President,
in the Chair.

The discussion on Mr. Francis Fox's Paper, "The Simplon Tunnel," occupied the evening.

22 January, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President,
in the Chair.

(*Paper No. 3678.*)

“Internal-Combustion Engines for Marine Purposes.”

By JAMES TAYLER MILTON, M. Inst. C.E.

THE increasing use of internal-combustion engines on land, and their undoubted economy, have led to considerable interest being taken in their application to marine purposes. Already a large number of such engines have been fitted in small craft, principally on the Continent. In this Paper, however, these small engines will not be considered, except so far as they may furnish lessons in design for larger engines, which will be necessary if the internal-combustion motor should come into use for ordinary sea-going vessels.

The Author was led to give attention to engines of this kind in connection with proposals to fit them in vessels classed with Lloyd's Register; and he desires to thank Messrs. Beardmore & Co., Messrs. Rodger & Co., Messrs. Richardsons, Westgarth & Co., Messrs. Thornycroft & Co., Messrs. Crossley Brothers, Messrs. Hornsby & Sons, and also many of his personal engineering friends, for the information and experience regarding internal-combustion engines which they have placed at his disposal.

On land, internal-combustion engines have been made to use various fuels, namely, petrol, refined oils, heavy hydrocarbon oils, coal-gas, producer-gas, coke-oven gas, and blast-furnace gas. Of these fuels, petrol and refined oil, on account of their cost, are suitable only for very special vessels, and up to the present heavy oil and producer-gas are the only fuels which it is necessary to consider in connection with large marine engines. As regards producer-gas, only that made from coke, or from anthracite coal, seems at present to be available for marine work, but there is a reasonable expectation that a producer will be perfected soon which will enable bituminous

coal to be used without requiring the elaborate washing-arrangements which can be employed on land for freeing the gas from dust and tar. It is not intended, however, in this Paper to deal with the question of producers, but only to discuss the mechanism of the engine itself. Although the requirements for a successful marine engine are very different from those for a land-engine, it will be well first to glance at what is being done on land in the way of large installations.

Where very large powers are not required, the engines are generally single-acting with single cylinders, and as the four-stroke cycle is usually employed, this leads to large cylinder-volumes in proportion to the power generated, and it also necessarily involves the use of heavy fly-wheels. The largest engines of this type with which the Author is acquainted are some made by Messrs. Richardsons, Westgarth & Co., with cylinders $51\frac{1}{2}$ inches in diameter, 55 inches stroke, running at 80 revolutions per minute, and indicating upwards of 800 HP. These makers, however, have ceased to build this kind of engine, and for large powers they make double-acting two-cylinder tandem engines. Of these they have made several sets with cylinders $29\frac{1}{2}$ inches in diameter, $35\frac{1}{2}$ inches stroke, running at 110 revolutions per minute, and giving about 850 I.H.P. per pair of tandem cylinders. Messrs. Crossley Brothers have made engines of almost identical dimensions. The Deutz Gas-Motoren Fabrik have made tandem double-acting engines up to 2,000 I.H.P. with two cylinders. Messrs. Rodger & Co., of Glasgow, have made large vertical engines resembling the marine type. Other makers have also made large and powerful engines, and the experience of detail necessary to make the large cylinders capable of withstanding the shocks of explosion and the high temperatures of the burning fuel is therefore easily available if the other mechanical requirements are complied with.

Much useful information upon the latest experience with land engines is given in three Papers recently contributed to the Iron and Steel Institute.

For marine purposes the largest set the Author is acquainted with has been made by Messrs. Beardmore & Co., of Dalmuir.¹ These engines are intended to use producer-gas, but they have not yet been put to work at sea.

The next in point of size are engines on the Diesel principle using heavy mineral oil: they have been fitted in two vessels trading in the Baltic.

¹ For particulars see Transactions of the Institution of Naval Architects, vol. xlviii (1906), p. 112.

Nearly all of the small craft fitted with internal-combustion engines use heavy oil as a fuel.

The special conditions to be satisfied by a successful marine engine are :—

- (a) The engine must be reversible.
- (b) It must be capable of being stopped quickly and of being started quickly either ahead or astern.
- (c) It must be capable of being promptly speeded to any desired number of revolutions between dead slow and full speed, and of being kept steadily at the required speed for any length of time. "Dead slow" ought to be not faster than one-quarter of full speed, and should be less than this in very fast vessels.
- (d) It must be capable of working well, not only in smooth water, but also in heavy weather in a seaway in which the varying immersion of the propeller causes rapidly changing conditions of resistance.
- (e) All working parts must be readily accessible for overhauling, and all wearing surfaces must be capable of being promptly and easily adjusted.
- (f) The engine must be economical in fuel, especially at its ordinary working-speed.

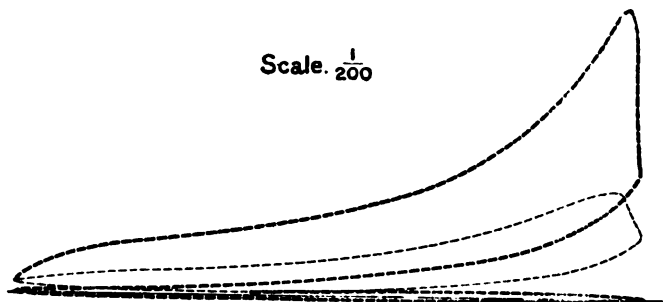
In small engines condition (a) is not complied with : the engines are always run in one direction, the reversing of the vessel being provided for either by a reversing-bladed propeller or by the intervention of toothed gearing. Condition (b) also, in small engines, is fulfilled by means of a friction-clutch arrangement which permits the engine to be kept running while the screw-shaft is stopped. For large sea-going vessels, however, condition (d) practically puts movable-bladed propellers, clutches, and toothed gearing entirely out of question, and necessitates a reversing engine, with a direct drive on to the screw-shaft, and a fixed propeller. In large engines, also, conditions (b) and (c) prohibit the use of a heavy fly-wheel, and necessitate a fairly equable turning-moment at all working-speeds.

In marine engines the revolutions are practically proportional to the speed of the ship, and as the vessel's resistance increases much more rapidly than the speed, it follows that the mean effective pressure in the cylinders must be capable of being reduced in very much greater ratio than the speed of revolution. For instance, at one-half of full speed the power exerted is less than one-eighth of the full power, so that the mean effective pressure is less than one-fourth

of that at full power; whilst at dead slow, say at quarter-speed, the mean pressure would be only about one-sixteenth of that at full power. This great range of mean effective pressure is very difficult of attainment, especially as a fly-wheel is not admissible, so that the reduction of power by the suppression of, say, alternate fuel-charges is not practicable.

In considering the turning-moment and how it affects the lower limit of speed of revolution, it may be pointed out that in a steam-engine the mean pressure can be reduced in almost any desired degree by throttling the steam-inlet. In an internal-combustion engine, however, there is not nearly the same possibility of range. The pressure may be reduced, but only in a certain ratio, by cutting off part of the fuel-supply though not the air-supply. Below this point the mixture will be too poor to ignite. Even at the critical point at which ignition is just possible, the mean pressure produced

Fig. 1.



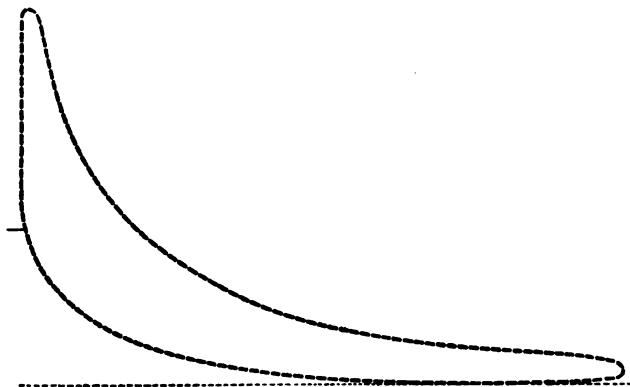
is comparatively high. If the ratio of mixture of air and fuel is kept at an inflammable point, and the supply is throttled, a reduction of pressure is obtained; but there is a limit to this also, because the clearance-space is in most engines left filled with burnt gas at atmospheric pressure, and this dilutes a too-greatly enfeebled charge below the ignition-point. The indicator-diagram shown in Fig. 1 is from a Crossley gas-engine. The heavy diagram represents the working at a full charge, the lighter diagram that with the charge reduced to about as low a point as is practicable. At the full power the mean effective pressure is 81·3 lbs. per square inch, whilst at the low power it is 36·8 lbs.

In a marine engine this reduction of mean pressure would represent a reduction of speed of revolution of only 32 per cent.; in other words, if speed could be reduced only by such reduction of charge as in this instance, in a vessel whose full speed was

10 knots per hour, no speed less than $6\frac{1}{2}$ knots per hour could be attempted without the engines stopping.

The question of the effect of a fly-wheel upon the steadiness of the motion of an internal-combustion engine was dealt with by Mr. James Atkinson, of the firm of Messrs. Crossley Brothers, in January, 1906, in a Paper read before the Manchester section of the Institution of Electrical Engineers. His Paper took full account of the effect of inertia of the reciprocating parts of the machinery, and showed that with the actual weights of the single-acting single cylinder that he was considering, the turning-moment varied from 7·7 times the mean moment in a forward direction to about 1·5 times the mean moment in the reverse direction; in other words, the total variation of load on the shafting was more than nine times the stress due

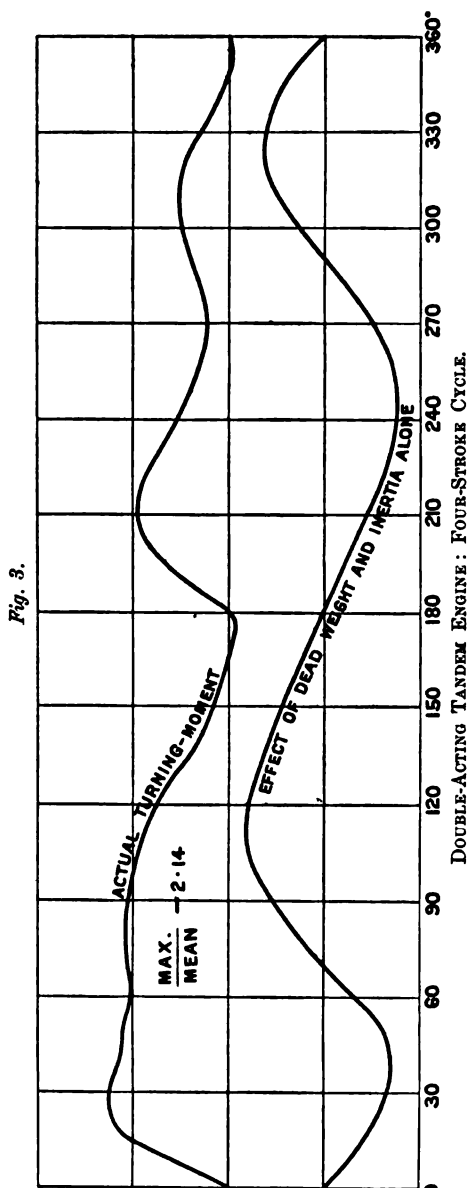
Fig. 2.



to the mean load. Such an engine is out of consideration for marine purposes.

While the four-stroke cycle is retained, the minimum number of cylinders necessary to give always a positive turning-moment is four single-acting or two double-acting; and even with these numbers of cylinders the turning-moment will vanish at the dead points, and the engine will have all the irregularities of motion of an ordinary single-cylinder steam-engine.

It will be well to examine the turning-moments of the double-acting tandem engine, which is the simplest engine employing the four-stroke cycle that will work without a fly-wheel or its equivalent. *Fig. 2* represents an actual indicator-diagram of a horizontal engine of this type by Messrs. Richardsons, Westgarth & Co.; but, as marine engines are almost invariably made vertical,



this diagram will be taken as representing the cylinder-pressures of a vertical tandem engine of the same diameter and stroke. In such an engine, besides the effect of the inertia of the reciprocating parts, there are also to be considered the weights of the parts themselves, as the weight acts in conjunction with the forward pressure on the down stroke and in opposition to it on the up stroke. Assuming the length of the connecting-rod to be of the usual proportion, namely, four times that of the crank, the upper curve in Fig. 3 represents the actual forward turning-moment of the engine in each revolution due to the four impulses which occur every two revolutions.

It will be seen that, owing to the effect of the compression, there is actually a slight negative moment just before the two dead points. The ratio of maximum turning-moment to the mean or useful work is 2.14:1. The lower curve in this diagram represents separately the effect of the dead weight and of the inertia of the moving parts which have been included in the turning-moment curve. If two

such engines, having the cranks at right angles, be combined, the power is of course doubled, but at the same time a more equable movement is obtained, there being at no point a negative moment, while the ratio of maximum to mean moment is reduced to 1.75:1.

When three cranks and three pairs of tandem cylinders are used the turning-moments are as shown by the lower curve of *Fig. 4*. The motion is still more equable, the ratio of maximum to mean being reduced to 1.31:1.

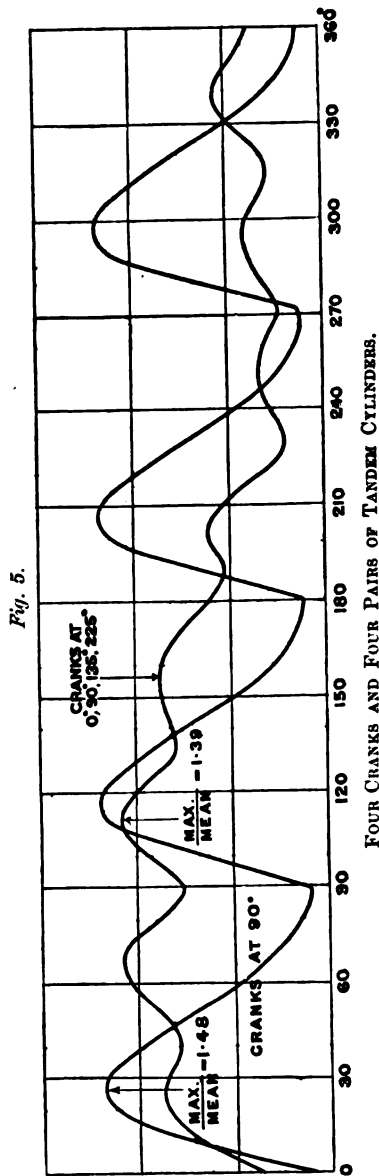
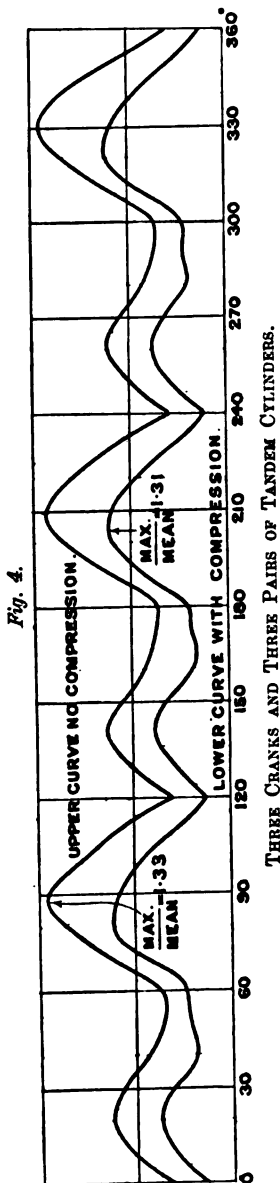
When four cranks and four pairs of tandem cylinders are employed, the turning-moments are as in *Fig. 5*, one curve showing the case in which the cranks are set at equal angles of 90° , when the ratio of maximum to mean is 1.48:1, the other curve showing the case in which the cranks are at angles of 0° , 90° , 135° and 225° , when the ratio of maximum to mean is 1.39:1.

It will be seen that the increase from three to four cranks has not been an improvement. This leads to the conclusion that an ordinary internal-combustion engine with three cranks will probably, on the whole, give the best results from the point of view of smoothness of running.

It has been mentioned that a reduction of 55 per cent. of the mean pressure—probably about the greatest that can be obtained in an ordinary internal-combustion engine by the enfeeblement of the charge—leads only to a reduction of 32 per cent. of the speeds of rotation and of the vessel, if the engine works with all the cylinders charged: it will of course be possible, in a three-crank engine with double-acting tandem cylinders, to cut out entirely one set of cylinders, say the top set. This will reduce the effective mean moment by one-half, and in consequence the speed of revolution will be reduced by about 30 per cent. The effect of this on the turning-moment is shown for two revolutions in *Figs. 6*, which give the moment both for one cylinder only and for the combination of the three cylinders. The latter curve shows that the engine will still run with three cylinders working, there being always a positive turning-moment.

If, besides cutting out half the cylinders, it is possible to reduce the mean pressure in the remaining cylinders in the same proportion as in the diagram for the Crossley engine (*Fig. 1*), the result will be a reduction of the effective moment to $22\frac{1}{2}$ per cent. of that at full power, and of the speed of revolution to a little less than half that of full power. This is a better range of speed than is obtained by reduction of pressure only in all the cylinders, but it still is not satisfactory for marine work. It is doubtful, however, whether the

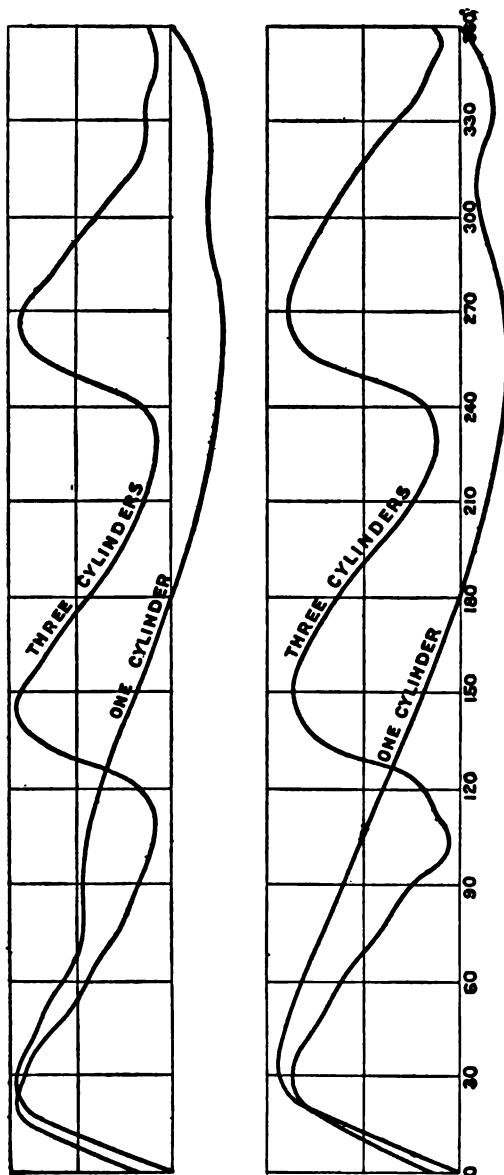
engine would run with so great a reduction of charge. The subject of a greater reduction of speed will be referred to later on.



It will be convenient here to state briefly the principles involved

in the four-stroke-cycle internal-combustion engine, in order to

Figs. 6.

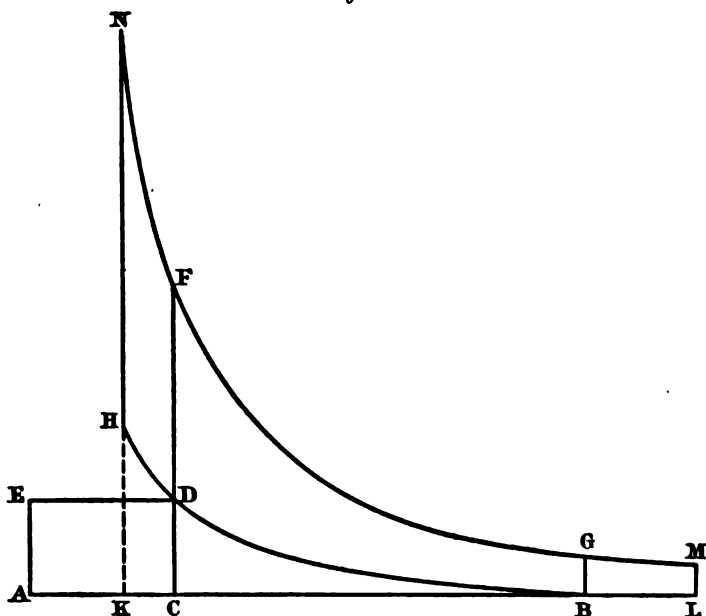


DOUBLE-ACTING TANDEM ENGINE WITH THREE CRANKS, WITH ONE AND WITH THREE CYLINDERS.

see what modifications are desirable or possible for introducing it into marine work.

In *Fig. 7*, AB represents the total capacity of the cylinder, AC being the clearance-space, CB the volume swept through by the piston. At the commencement of the cycle there is a volume AC of burnt gases in the cylinder at about the atmospheric pressure; the first stroke draws in a volume CB of combustible mixture also at about atmospheric pressure. The second stroke compresses the mixture of burnt and unburnt gases into the volume DE (= AC) of the clearance-space, the compression increasing the pressure to DC above the atmosphere. At this instant ignition takes place, the heat generated increasing the pressure to CF. On the third stroke the

Fig. 7.



hot burnt gases expand till they fill the whole cylinder-volume, and at the termination of the stroke they have the pressure GB. On the fourth stroke the larger portion of the gases is exhausted from the cylinder, leaving the volume AC at about atmospheric pressure to take part in the next cycle.

During the second stroke an amount of work represented by the area BDC has to be done in compressing the gas, and during the third stroke an amount of work, represented by BCFG, is performed by the gas, the area BDFG representing the net work obtained during the cycle.

It will be observed that at the commencement of the exhaust the gas-pressure represented by GB is still very considerable, and that the energy represented by this pressure is not utilized in the engine. For instance, in the Richardsons-Westgarth engine, which has been referred to, the terminal pressure is 32 lbs. per square inch above the atmosphere, whilst in the Crossley engine it is about 40 lbs. In marine engines it is generally considered that the expansion of the steam may be usefully carried so far that the terminal pressure shown on the indicator-cards is not more than 6 lbs. or 7 lbs. above the back pressure. Greater economy could therefore be realized in the internal-combustion engine if by any means a greater expansion could be obtained when using the same quantity of fuel. For instance, if the volume could be increased to AL additional work represented by the area LBGM would be obtained.

Turning to the other end of the diagram, it will be seen that if the working-volume could be increased by an amount which would reduce the clearance to AK, an addition to the work would be made represented by the area DHNF, whilst the addition to the fuel-charge would be represented by only the volume KC; and as the pressure in this volume KC is always much greater than the mean pressure, it is seen that the useful work done by increased compression is always proportionately greater than the excess of charge used. The smaller the clearance-spaces, therefore, the greater will be the economy, but the greater also will be the work which has to be done during compression, and the greater will be the initial pressure at ignition. Further, as compression is always accompanied by a rise of temperature, an excessive compression might be accompanied by so high a temperature as to cause premature ignition. It is the necessary limitation to the safe initial pressures and compression-temperatures which determines the possible range of economy obtainable at this end of the diagram. In the Richardsons-Westgarth engine to which reference has been made, the initial forward pressure in the cylinder is 450 lbs. per square inch above the atmosphere, and in the Diesel engine a pressure of 600 lbs. per square inch is often reached. Although an increase of economy obtained by reducing the clearance necessitates high pressures within the cylinders, whilst that obtained by increasing the expansion involves only lower cylinder-pressures, yet, on account of the larger area of cylinder that the latter requires, any given increase of area at the right hand of the indicator-diagram involves higher loads on the piston-rods, connecting-rods, and crank-pins than an equal increase of area made on the left hand of the diagram.

As the compression-stage of the cycle always precedes the impulse, some auxiliary power is necessary for starting the engine by giving

the first turn round. In small launch-engines hand-power may be used, but with larger engines mechanical means have to be applied, the most usual being the use of compressed air supplied by auxiliary mechanism. For large engines, therefore, a separate air-compressing engine, combined with adequate storage-capacity, is a necessity, and this in spite of the fact that one-half of the functioning of all the main cylinders is taken up in gas-compression.

If the necessary compression for ordinary working could be performed in a separate cylinder, the compressed gas being stored in a suitable receptacle and admitted to the main cylinders at the commencement of the stroke, the main engine could be made a two-stroke cycle instead of a four-stroke cycle, and the same size of main cylinders would then yield considerably more than double the power obtained where the four-stroke cycle is used. Referring again to *Fig. 7*, the work at each end of the cylinder per two revolutions would in a two-cycle engine be twice the area BCFG, instead of, as in the four-cycle engine, once the area BDFG; but in this case the gas-compressors would have to be capable of doing during the same time the work represented by twice the area BAED. In other words, by separating the work of compression and expansion into two different sets of cylinders one set only will have to be made to withstand the excessive pressures and temperatures of combustion, and this set will be of smaller diameter, for the same net work, than the cylinders employed in the usual way, whilst the other set will have to be made somewhat larger, but will have to withstand only the pressures and temperatures due to compression. The change will be accompanied, however, by a considerable loss of efficiency, due to the excess of work required in forcing the gas out of the cylinder into the receiver, from which it will pass into the clearance-space of the main cylinder without giving up a corresponding amount of work.

As an instance, consider the Richardsons-Westgarth engine again. In *Fig. 4* the lower curve has already been given as representing the turning-moment of a three-crank six-cylinder double-acting tandem set of engines working on the ordinary four-stroke cycle. The upper curve represents the turning-moment of a three-cylinder three-crank double-acting set of cylinders of the same size, in which the compression is performed in a separate set of cylinders. In the former case the ratio of maximum to mean turning-moment is $1.31 : 1$; in the latter case the ratio is nearly the same, namely, $1.33 : 1$, but the mean turning-moment is increased by 26 per cent., whilst no extra stress is put upon the pistons, piston-rods, or connecting-rods. The loss of economy incidental to this change is,

however, very large, being equivalent to a mean increase of back pressure of more than 25 lbs. per square inch, or a loss of more than 30 per cent. If the separation of the compression from the expansion-cylinders were necessarily coupled with so great a loss of efficiency, it would be useless to discuss it, even although it would entirely solve the problem of being able to run the engine at low speeds. This, however, is far from being the case.

Referring again to *Fig. 7*, this time as an ideal diagram of an engine with separate compressing- and expanding-cylinders, for the compression of the charge and forcing it into a separate receiver the cylinder requires to be made with a working-capacity equal to AB, which is the working-volume plus the clearance-space of an ordinary engine using the same amount of mixture. This cylinder also requires to be made with the minimum amount of clearance, so that the whole of the charge is forced out at each stroke. The work done in compressing the charge up to the pressure of the receiver is BCD, and CAED is the further work done in forcing it out of the cylinder into a receiver. If, in the same way, the expansion-cylinder be made with a working-volume equal to the volume plus clearance of the ordinary type of engine and with practically no clearance, then, by admitting the charge from the receiver into a portion of the stroke equal to AC before ignition, an amount of work is returned by the compressed mixture which is equal to that expended in pushing it out of the compression-cylinder. If it be then fired the remaining part of the diagram is obtained as before. The net result is that the same total useful work is obtained with the same charge as before, or, in other words, there is no loss in economy. Further, as it is no longer necessary to make the main cylinder the same size as the compression-cylinder it may be made still larger—say, with a total volume equal to AL—and then the further work represented by the area LBGM will be obtained from the same charge. This is an actual gain of economy.

Although the changed design involves the use of somewhat larger cylinders, it leads to many incidental advantages. There being no clearance, there will be practically no burnt gases left in the expansion-cylinder, and the amount of the charge can therefore be reduced not only by an earlier cut-off but also by throttling, without the risk of diluting it below the ignition-point. By an earlier cut-off, retaining the same admission-pressure and the same quality of charge, a greater expansion can be obtained and therefore greater economy at powers somewhat below the full power. With an earlier cut-off, accompanied by a reduced admission-pressure, the combustion of the charge can still be accomplished, and at the same time the mean pressure can be

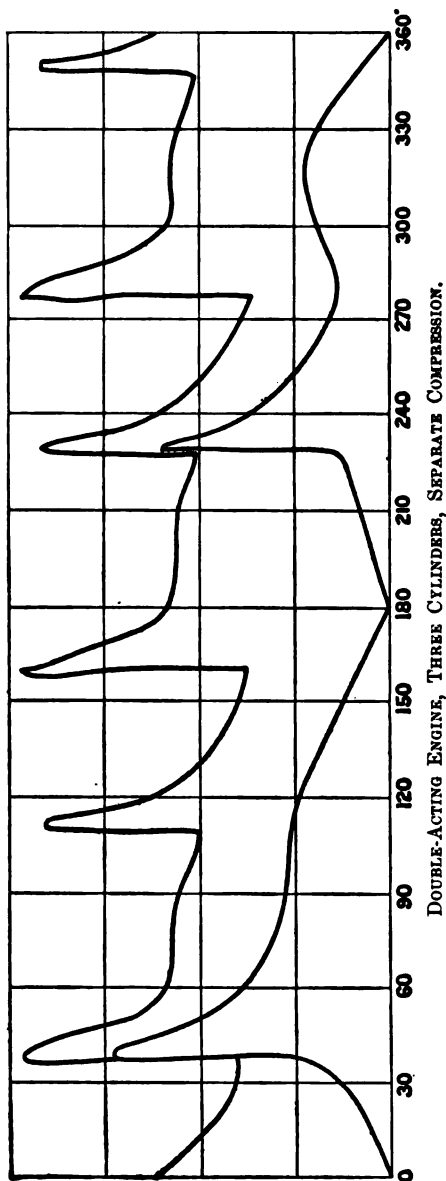
lowered very considerably below that obtainable under any ordinary

working-conditions with the four-stroke-cycle arrangement involving large clearance-spaces; and with this reduction of pressure a far greater range of speed is possible.

Among other incidental advantages may be mentioned the fact that, as the cycle is a two-stroke one, there will be an entire suppression of the 2-to-1 gear for actuating the admission- and exhaust-valves, it being possible to provide for the necessary valve-movements and also for their requisite adjustability, both for variations of speed and for reversing, without the intervention of any toothed gearing. This is a point which will appeal to all marine engineers.

The turning-moment of such an engine as that indicated above is shown in *Fig. 8*, calculated from the indicator-diagram shown in *Fig. 9*, which is the same pressure-volume curve as has been used before, but

Fig. 8.

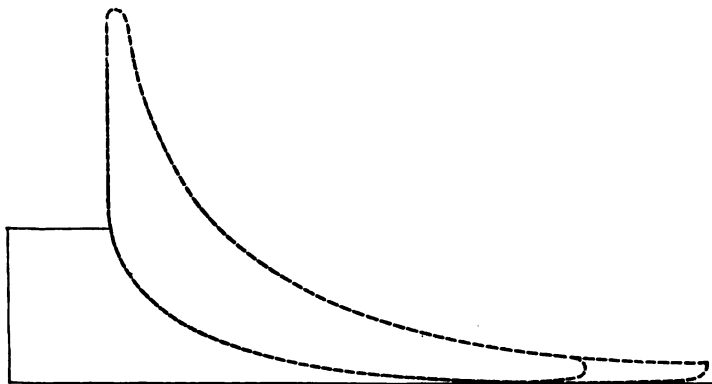


with the stroke increased by the clearance required in the engine

from which this diagram was taken. The necessary allowances have been made for the effect of the reciprocating weights due to the altered condition of the design. The peaks shown in *Fig. 8* are of course due to the supposition of the ignition occurring instantaneously, which, however, will not actually happen; but even on this supposition it is seen that the resulting motion is not incompatible with good working, the ratio of maximum to mean moment being only 1.55:1.

With regard to the separate compression-cylinders, *Fig. 2* shows that at the commencement of the compression-stroke the cylinder is not actually full of the charge at atmospheric pressure. In fact, with fast-running engines it is impossible to draw in the full volume of the charge. In the particular case illustrated, the cylinder is only

Fig. 9.



about three-quarters full. With separate compression-cylinders, larger air- and gas-inlet valves are possible, and fuller charges can be introduced, so that in the supposed engine it would be quite sufficient to make the working-volume of the compression-cylinder equal to or even slightly less than that of the ordinary engine with which it is compared, instead of making it equal to the full volume plus clearance. But it will doubtless be found advisable to divide the compression—or at least that of the air—into two stages. By this means a much more equable turning-moment is required for the compression-mechanism than is needed where a high degree of compression has to be obtained by one stage.

In oil-engines it is only necessary to provide for the compression of the air: in gas-engines both gas and air have to be compressed. This may be done after their mixture, but preferably they should be

separately compressed and only become mixed as they enter the cylinder. In the latter case, if the gas is maintained at a pressure slightly higher than that of the air, there will be no danger of an air-leakage into the gas and no risk of explosion by back-fire in ordinary working-conditions.

The compression of the gas or air is necessarily accompanied by a considerable increase in temperature, in fact, in some of the oil-engines in successful use this feature is necessary for the ignition of the charge. Where compressed air is required for industrial purposes the heat produced by the compression is purposely abstracted and is wasted, but in the case under consideration this will not be necessary, and beyond the cooling by the cylinder-walls, the lubrication of which will not present greater difficulties than that of the main engine-cylinders, there need be no abstraction of heat.

It will probably be found to be advisable for the main engine to take its charge directly from the pipe between the compressor and the receiver, not from the receiver itself; the heat of compression will thus be received in the main cylinders practically as soon as it is produced, instead of being dissipated in the receiver. Further, in the opening of the receiver, through which there will be constantly an ebb and flow of some small part of the air-charge, there may, if necessary, be fitted a regenerator which will retain the heat of the hot gas entering the receiver and will raise the temperature of the cooler gas leaving it.

An engine on these lines can be made with the compressors driven from the main-engine crank-shaft, in which case the net available power is the difference between that developed in the expansion-cylinders and that utilized directly in compression. It is, in fact, the same power as is available from the same charges in the ordinary four-stroke-cycle engines, and, as has been shown, the suppression of the clearances enables a much lower speed to be obtained when necessary. By the complete separation of the compression, however, that is, by performing it by means of a separate engine, it will be possible for any required degree of slowness to be obtained by suppressing the whole of the fuel-supply and admitting compressed-air only to the cylinders; and as a supply of compressed-air is always required for starting-purposes, and must be provided by some auxiliary appliance, the most convenient arrangement will be for the compressors to be driven independently of the main engines.

In conclusion, to fix ideas as to required dimensions of cylinders, a three-crank tandem set of engines working on the ordinary

four-stroke cycle will be taken, the indicator-diagram of which is shown in *Fig. 2*. If each of the six cylinders be 30 inches in diameter, the water-cooled piston-rods 5 inches in diameter, the stroke 3 feet, and the speed 100 revolutions per minute, then, with an effective mean pressure of 86·5 lbs. per square inch, there will be obtained, say, 3,250 I.H.P. Such an engine could not be reduced in speed below 65 revolutions per minute without risk of stopping.

In the proposed arrangement of separate-compression engines with the two-stroke cycle any required slowness could be obtained. The mean forward pressure would be 119 lbs. per square inch, and for the same indicated power, namely, 3,250 I.H.P., there would be required, if the same stroke and speed of revolution were retained, three expansion-cylinders 25½ inches in diameter. Allowing a mechanical efficiency of 0·85 for the compressing-gear, about 1,450 HP. will be necessary. If performed in two stages, the compression would require, say, two double-acting air-cylinders about 31 inches in diameter for the first stage, and two double-acting cylinders about 18 inches in diameter, or one double-acting cylinder about 25 inches in diameter, for the second stage, the necessary power being obtained from a pair of ordinary four-stroke-cycle tandem engines with four cylinders 24½ inches in diameter, or one tandem set with two cylinders 34½ inches in diameter, assuming the same piston-speed as before for all the cylinders.

The compressor-engines might be fitted with a fly-wheel, and as they have to work against a comparatively fixed resistance, proportional to the receiver-pressure, they could be speeded as desired without difficulty.

The increase in the number of cylinders due to separating the compression from the main engine is a disadvantage; but although the total cylinder-capacity is greater, the diameters of the cylinders are smaller, and only half of them are subject to the high temperatures and pressures of the burning fuel; so that, on the whole, it is thought that the advantages of the arrangement more than compensate for the increased number of working parts.

The Paper is accompanied by three drawings, one tracing and one sun-print, from which the Figures in the text have been prepared.

Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author, remarked that the Paper was the first that had been read before the Institution on the subject of the use of internal-combustion engines for marine purposes, but he felt sure it would not be the last; the younger members of the Institution, at any rate, were likely to hear a great deal on the subject later on. The Paper was largely confined to dealing with one particular aspect of the internal-combustion engine—the question of variable speed and balancing; but the discussion could take place upon any subject connected with such engines, even though many of the points had only been very briefly touched upon by the Author.

Mr. Dugald
Clerk.

Mr. DUGALD CLERK observed that the interesting subject of the Paper admitted of a great variety of opinions, and he thought the Author would not be surprised to learn that although he agreed with him on some points he differed from him upon others. It was very interesting to Mr. Clerk, as an engineer accustomed to design gas-engines, to have the ideas of a steam-engineer upon a problem that had occupied his mind and work for about 30 years. He need hardly say that the question of the application of internal-combustion engines to the propulsion of ships was one which had occupied his attention; and at the present moment he was designing engines which he hoped would fulfil that purpose. He agreed with the Author in, for example, the list of requisites for a marine gas-engine of large power; there was no doubt that it was necessary to get rid of everything that might be described as "motor-car tricks." In the motor-car and the motor-boat the power was so small that it was possible to introduce clutches and reversing spur-gearing, but anything of that kind was entirely out of place, and would be exceedingly dangerous, in a large gas-engine for marine purposes. He also agreed with the Author that the idea of separating the pump and the motor-cylinder was a very fascinating one, and if it were possible to suppress the whole negative work of the gas-engine the problem of driving a ship would be nearer solution. He agreed with him more particularly because the cycle which the Author proposed was one which had attracted his own attention very early. In 1878 he built a gas-engine which gave the diagram shown in *Fig. 9*; the engine was supplied with a compressing-pump, taking in gas and air, and compressing the gas and air into a reservoir. The

mixture was taken into the engine-cylinder during the first portion of the motor stroke, just as was indicated in *Fig. 9*; then the ignition took place when the cut-off closed, and there was a somewhat rapid rise—in some cases too rapid; and then an expansion-curve was obtained as shown in *Fig. 9*. That engine was exhibited at the Kilburn Show of the Royal Agricultural Society, in 1879, and he believed it was the first compression-engine giving an impulse every revolution that was ever built. Unfortunately, although that type of engine was a very fascinating one, and had many advantages, it presented certain difficulties, some, but not all, of which the Author appeared to have realized. It was possible to get with it very high economy and a good operating engine; but its very pronounced disadvantages had induced Mr. Clerk to design a new type, a two-cycle engine—he had mostly worked on two-cycle types—and that engine appeared for the first time in Paris in 1881. It embodied the well-known Clerk cycle which was now used on a large scale in the large Körting and Oechelhäuser engines built in Germany and Great Britain. That cycle, however, also had disadvantages—all gas-engines had disadvantages of one kind or another—and in 1886 he again attempted to build engines giving a diagram such as *Fig. 9*, and succeeded fairly well. He built a number of very economical engines, but they were found to be too delicate for ordinary small-engine work: the adjustments were too sensitive. In the early engine of that type one of the chief difficulties was the necessity of compressing the gas and air to the full pressure, of admitting that gas and air into the motor-cylinder at that compression, and of then igniting the mixture. The interval allowable between the ignition of the mixture and the closing of an admission-valve was very small, because at that time the piston was beginning to move at its maximum rate; and the consequence was that, if the ignition was not brought on sharply, whenever the admission-valve shut the ignition would occur very far on in the stroke, and the effect would be at once to reduce the expansion and the power. In order to avoid that, the tendency was to bring the ignition on rather too soon, and if the speed of the engine slackened a little, occasionally, but not very often, the flame was too quick and passed back into the reservoir, and the whole of the reservoir was put under the maximum explosion-pressure; that was to say, if the working-pressure was about 200 lbs. per square inch the reservoir had to withstand that pressure. But there was a worse difficulty than that. It was possible to make the reservoir withstand 200 lbs. per square inch, but before the engine could begin working again on

Mr. Dugald Clerk.

Mr. Dugald
Clerk.

usual cycle, enough gas and air had to be pumped into the reservoir to clear out the products of combustion formed therein. The consequence was that in his next attempt to make an engine operating upon the cycle which the Author had described, he made up his mind to omit the reservoir, because before the speed picked up again, if there was any load on the engine, the engine often stopped. In the engine of 1886 and 1887, which he had had the honour of describing¹ to the Institution in 1896, he arranged a pump at the side of the motor-cylinder with the minimum of clearance between the pump and the motor, the pump being so arranged, in regard to its crank-angle, that when the motor-piston began to move forward communication was made through a short port of small capacity, with the result that the pump forced the charge into the motor-cylinder just as it was compressed, without any intermediate reservoir. That method had been applied also by Mr. Atkinson, now of Messrs. Crossley Bros. and then of the British Gas-Engine Company, and Mr. Clerk thought that Mr. Atkinson and himself must have built engines of that type numbering in the aggregate about forty or fifty—engines that were actually in use, giving fairly good results, but also giving trouble from the delicacy of the ignition-adjustment. It was true that the Author's engine was meant to work at a lower speed. The Author proposed about 90 or 100 revolutions per minute, and at that speed he would have less trouble in getting the ignition properly timed, but he would have a diagram somewhat different from the one he had shown. The Author's diagram (*Fig. 7*) had a level admission and then a straight run up, but the fact that the valve took time to close and time to open, would round off the diagram, and when the valve cut off it would cut off some time before ignition occurred, and immediately the valve cut off the pressure began to drop. [The speaker drew an illustrative diagram on the blackboard.] Diagrams of that character would be found in Mr. Clerk's Paper read before the Institution in 1896. Then, although the ignition, whether flame or electric, might be brought on very quickly, the flame took considerable time to travel through the whole cylinder and yield the maximum pressure, and consequently even at the best a diagram was obtained with a sloping rising line, as in *Fig. 40* of his 1896 Paper.² If the ignition happened to fail a little longer than usual, a diagram might be obtained like *Fig. 41* in the same Paper. If, as was usual in large engines nowadays, the gas had

¹ D. Clerk, "Recent Developments in Gas-Engines." Minutes of Proceedings Inst. C.E., vol. cxxiv, p. 96.

² *Ibid.*, p. 125.

been admitted at one-sixth or one-seventh, and then cut off and fired, it was probable that before there was any real effective maximum pressure something like one-quarter of the total stroke had been reached. That reduced greatly the mean pressure possible and also the economies. He would be very proud if the Author succeeded in running the engine, because it was one that had interested him for many years, the only point of difference being that the Author drove the gas- and air-pumps separately. It was true that by supplying the gas and air separately to the cylinder the ignition into the reservoir would be avoided, but there were certain difficulties even there. That method had been tried by Mr. Atkinson and himself independently. On the whole, in the present stage of knowledge, until the Author had built an engine of that cycle and shown that he had overcome all the difficulties that puzzled the rest of his fellow-workers, Mr. Clerk preferred the well-known Otto cycle, and next to that he preferred the Clerk cycle, although on the whole he thought the Otto cycle was the safest. The Clerk cycle with a clearance-space at the end, exhaust ports over which the piston ran, and the displacing arrangement, gave all the advantages that the Author called for, without the loss of pressure to which he referred. With the Otto cycle, however, although there was, no doubt, the disadvantage of the one explosion for two revolutions, yet there was an advantage in certainty of charging, in the certainty that exactly the expansion arranged for was obtained, and in ease of operating the valves. The valves in the Otto cycle could be operated with much ease because there was plenty of time to raise them and drop them at the end of the stroke. The Clerk cycle had the slight disadvantage that the valve was operated rather quickly, because little time was allowed in exhausting on the out exhaust ports. Consequently he would place in order, first the Otto cycle, with perhaps a six-cylinder engine if single-acting, or a three-cylinder engine if double-acting, and secondly, the well-known Clerk cycle; although he would be very glad to see an experimental engine built of the type described by the Author. He had no doubt it could be made economical, but there would be great difficulty in preventing back ignition and consequent reduction of the economy. He hoped the Author would not feel that in criticizing the Paper Mr. Clerk was in any way adverse to his ideas.

Professor F. W. BURSTALL felt disposed to wonder sometimes whether steam-engineers quite realized all the minute difficulties that had to be dealt with in gas-engines of any dimensions. He could speak somewhat feelingly on that subject, as he had

Mr. Dugald Clerk.

Prof. Burstal

rcf. Burstall. lived for about $2\frac{1}{2}$ years in daily touch with a high-compression gas-engine and he knew what the difficulties really were. In the light of his own experience he was very glad that he had not the job of running an experimental gas-engine built on the lines the Author had indicated. Mr. Clerk had given his experience of the early two-stroke-cycle engines, but had not alluded to the fact that in those days, with coal-gas, they worked at very low compression, that was to say, at probably 50 to 60 lbs. per square inch. When power-gas was used, in order to get economical working it was necessary to go to much higher pressures. With producer-gas of the Dowson or Mond type it was necessary to run at 100 to 110 lbs. per square inch compression, and on blast-furnace gas even higher. Increased compression introduced great difficulties, which were entirely absent from the small gas-engines hitherto used. He would allude to the action that took place later on, and would merely state there that, while those cycles might answer perfectly well on 55 lbs. per square inch compression, they were at least risky with high compressions. The first point he desired to comment upon was the fact that the Author did not say anything about the difficulty of building large vertical gas-engines. It was assumed that because it was possible to build a big horizontal engine it was also possible to build a big vertical one. In the course of the last 7 or 8 years he had probably seen forty or fifty vertical gas-engines, ranging from 200 to 1,500 HP., and not one of them was what he would call a real commercial success, suitable for the onerous work of driving a ship at sea. Why the big vertical engine was not a success he could not say, but he knew there were problems to be solved in a vertical gas-engine that did not exist in the horizontal gas-engine. In the second place, the Author alluded to the need of reversibility, but gave no clue to the solution of this very difficult problem. The only way of reversing a four-stroke-cycle engine was by having some method of disengaging the valves; the whole cam-shaft must be disengaged, slipped round through half a revolution, and re-engaged again, while in the meantime the compressed air must be put on to stop the engine and to start in the opposite direction. The whole operation required very complicated mechanism to effect it. Reduction of speed was, of course, a simple matter. Anyone who had driven a six-cylinder motor-car knew that it was possible to drive through very wide ranges of speed without a change of gear; all that was required was to alter the lead of the ignition-spark and to cut down the charge. He did not wish to say that the same thing could be done in the present instance, but would just say what he had done on the gas-engine at the Birmingham University. There

were two methods of governing: quantity governing, that was Prof. Burstall. reduction of the total quantity of mixture, and quality governing, by reduction of the gas alone. As to quantity governing, it was perfectly correct to say that it was not possible to go below a certain point in a non-scavenging engine, but with a scavenging engine it was possible to go very low. The objection to quantity governing in land engines was of course that it made the mechanical efficiency very poor at light load, owing to the back pressure of the piston; and moreover it caused the lubricating oil to be sucked into the motor-cylinder and gave rise to serious incrustation. However, for marine purposes, there was no great objection, because for the most part the engine was running on full load constantly and then the mixture governing was quite as good as the other. In quality governing it was easy to reduce the mean pressure as low as was desired without cutting any charges out. He had worked at from 120 lbs. per square inch mean pressure down to 15 lbs. without cutting out a single charge, by the simple operation of altering the time of the ignition-spark, which of course had to be advanced as the load fell. That had been done with a compression of about 155 lbs. per square inch on Mond producer-gas; but there was no difficulty whatever in running an engine slowly, provided there were enough cylinders to equalize the turning-moment. With regard to the double action, double-acting cylinders, at any rate in the hands of English firms, had not been an unqualified success. The Germans, it was true, had succeeded, but it must be remembered that the German engine was relatively a larger engine than the English for the same power; moreover, most continental engines were built for blast-furnace gas, in which the problem was very much simpler. In view of all the difficulties of building a reliable marine motor, he suggested that it would be wise in the first instance to stick to single acting. He went a little farther than Mr. Clerk, and proposed a six-crank engine with twelve cylinders, the cylinders being arranged tandem one above the other. That gave a very convenient arrangement, as regarded both turning-moment and ease of throwing the compressed air into the top line of cylinders for both starting and reversing. The idea of separate compressor-pumps was by no means novel; he had known about it for nearly as many years as Mr. Clerk, and, like most people, he had been greatly fascinated by the more or less perfect analogy with the steam-engine: it looked so simple. He quite agreed with the diagram Mr. Clerk had drawn on the blackboard, but thought that probably it would be even worse. He would expect to find what he called a "flaming" diagram.

Prof. Burstall. He had found that the time of passing of the ignition-spark was always before the dead centre, even when there were no signs whatever that ignition had taken place before the dead centre; that was to say, the time which the mixture took to inflame was quite appreciable, and the speed of flame-propagation was evidently about the same as the piston-speed of the engine, which in his own case was 700 feet per minute. But even if a diagram such as *Fig. 9* were obtained, he did not think the results would be economical, viewed in the light of common practice. Economy was a relative term. What was economical 10 or 15 years ago was very poor now, and when he spoke of an economical engine he meant one using about 0.7 lb. of common coal per indicated horse-power-hour, or, put in another way, about 48 cubic feet of Dowson or Mond gas. In order to utilize that, it was necessary to have a compression of about 120 lbs. per square inch. If separate compression-cylinders were used, the temperature in the air-compressing cylinders would be something like 660° F., and that was too high to run without water-cooling the compression-cylinders. He might, perhaps, be met with the statement that the explosion-cylinders had to be cooled, and therefore it did not matter, but he thought he could show that it did matter. In the next place, the motor-cylinder was being subjected to a continuous series of explosions without any cooling at all. In the four-stroke cycle some cold air was drawn in, and the inner surfaces were cooled. When he said that the liner of such a cylinder as was mentioned in the Paper was $2\frac{1}{4}$ inches thick, it would be seen that the inner surface of the explosion-cylinder would become very much heated in spite of the water on the other side; in fact, it would become heated to such a degree that he would expect premature ignition of a violent character. In order to justify the point he had just made with regard to the jacketing of the pump-cylinder, he would give what he considered to be the action in the four-stroke-cycle engine, deduced from a large number of engine-trials. In place of starting with compression, he started with explosion. During explosion a large quantity of heat passed from the charge into the wall, and this heat continued to pass into the wall until the exhaust took place, and even possibly after. Thus the inner layer of the wall was heated to a temperature of perhaps 600° to 700° F. During the next stroke the exhaust was passing out, and the heat was sinking deeper into the wall until the suction-period was reached, when cold air and cold gas were drawn into the engine-cylinder. They began to take heat from the wall, and continued to do so, not only throughout suction, but throughout the greater portion of the compression. The wall, therefore, acted as a regenerator: it stored up heat on explosion, and

restored some of it on compression, and he ventured to think that Prof. Burstall. that was the reason why the four-stroke cycle was so economical. He had been unable to get accurate figures of the two-stroke-cycle engine of the present day, but certainly there was 6 to 7 per cent. difference in thermal efficiency between the two, and that he thought was very largely due to the regenerative action of the motor and pump being in one. It might interest the younger members to hear that all the information ever brought to light in connection with gas-engine work was contained in the patent-specification of Beau de Rochas dated 1857. He was unaware that anybody had ever found out anything on the subject of the economical utilization of gas that was not contained in that very remarkable work, all the more remarkable as being the conception of a man who could not have known anything of gas-engine work, inasmuch as no gas-engine of any kind had ever been built. He looked upon that patent-specification as almost an inspiration.

Engineer-Lieut. W. P. SILLINCE, R.N., had listened with great pleasure to the proposals of the Author, who had certainly dealt fully with the problem of adapting the internal-combustion engine to marine purposes. But he rather thought that gas-engines had gone on a little too fast. Nearly all the large gas-engines referred to by the Author employed either blast-furnace or coke-oven gas, and there was no difficulty in the matter of producers, because they used products which would otherwise be wasted. But, unfortunately, for the purposes of a ship it was necessary to consider the problem of making a gas-generator before making a gas-engine to use the gas generated. The Paper did not deal with the subject of the gas-producer, and he was afraid that the gas-producers had been rather neglected, particularly in England. Pressure gas-producers were under construction using bituminous coal, and of such size as to be capable each of supplying gas-engines of 3,000 HP.; but the gas-cleaning plant in connection with such producers would be much too bulky and heavy for use afloat; and, in addition, there were the risks of gas under pressure. Producers on board ship would have to be worked in confined spaces, and under these conditions gas-producers generating gas under a pressure greater than that of the atmosphere would be highly dangerous. The gaseous products obtained in the chemical reactions of these producers were nearly odourless and highly poisonous: he had once had a mouthful of such gas, and he did not wish for another. Given a battery of such producers in the confined stoke-hold of a ship, if there were even a small leak, the gas would accumulate, and,

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Lieut. Sillince.

being unable to escape owing to the difficulties of ventilating such confined spaces, trouble might ensue. It therefore appeared to him that it was necessary to see a further development of the suction gas-producer of comparatively large power. The difficulties were considerable, particularly when there was not one producer only, but a number in parallel, like a battery of boilers. Producers designed to be accommodated on board ship nowadays used anthracite or coke; if they could use hard steam coal, such as Welsh coal, it would be a great advance. To be able to use bituminous coal was perhaps the ideal state of affairs, but, as an intermediate step, a suction producer which could use such coal as an ordinary Welsh steam coal would be a great help in forwarding the solution of the problem of the propulsion of large vessels by means of gas-engines. He was afraid he was not in a position to criticize the experimental difficulties of such engines. He knew that gas-engines had peculiar difficulties of their own which were often hard to surmount; at the same time, there were certain points in the Author's proposals which appeared to him to be worth mature consideration. First of all, there was the separation of the compressor. Unlike most two-cycle engines in which the charge was compressed in the working-cylinder, and in which the period of exhaust was very short indeed, the Author's proposed engine would devote the whole of one stroke to the exhaust; and this would tend, in comparison with ordinary two-stroke-cycle engines, to dissipate those accumulations of heat which caused trouble in the working of the piston in the cylinder, the heating of valves, and so on, eventually ending in overheating or premature ignition. In the Author's engine there was one stroke devoted to exhaust, as there was in the four-stroke cycle, and it was to be hoped that an experimental engine would be built on some such lines. Economy under certain circumstances might be subsidiary to other considerations. It was unfortunate to see such a large amount of negative work in connection with a separate compression, although he was not sure that it need be much larger than in the ordinary cycle. For example, he noticed that if it were required to instal engines of 3,000 I.H.P. on the main shaft, it was necessary to carry compressors, of roughly, 1,500 H.P., together with the engine to drive the latter. Where weight was a consideration, this arrangement might be prohibitive, and whoever had to pay the bill might rather object to paying for 6,000 H.P. of an expensive type of machinery when only getting a net 3,000 H.P. out of it. As compared with the gas-engine, the oil-engine offered many advantages for marine purposes, principally due to the entire elimination of the gas-producing and gas-

cleaning plant, including the apparatus necessary for the generation of steam for the gas-plant. If oil-engines were to be utilized to any considerable extent for marine purposes they must be capable, except in very special cases, of using a cheap fuel, and one which was safe under all conditions of temperature likely to be found in machinery compartments, especially as it would, in all probability, be stowed either within, abreast of, or beneath such compartments. The question of the adequate supply of considerable quantities of such suitable fuel, if its use became general, would be a matter for serious consideration. It should be borne in mind, however, that an oil-engine which could deal successfully with residual oils, fuel oils, or crude oils of high flash-point and high viscosity, would work generally with much better results on refined oils of a lower flash-point if required; although the converse of that by no means applied. He agreed with the conditions laid down by the Author for a successful marine internal-combustion engine; but if internal-combustion engines were to be adapted for naval purposes there were certain additional conditions which should be complied with as far as practicable. First, the engine should be compact and as light as was consistent with good working and maintained reliability; secondly, the engine should be well balanced in order to avoid vibration-troubles; and thirdly, the design should permit of the machinery being placed behind armour protection, preferably entirely below the water-line. Of course in special vessels the last condition would have to be waived. The first condition, the limitation of weight and space, suggested the adoption of high piston-speeds and high speeds of rotation, whilst the second, the balancing, necessitated multi-cylinder engines unless balance-weights were fitted—and they were best omitted wherever possible. With an internal-combustion engine of given power and type it would generally be found that there was a certain piston-speed which it was undesirable to exceed. The speed of rotation at which the engine developed its power depended largely on the weight allowed, since the weight per horse-power decreased as the speed of rotation increased. When the speed of rotation and the piston-speed were decided on, a certain maximum stroke followed, associated with which there was generally a certain cylinder-diameter which it was desirable not to exceed. It therefore followed that, for an engine of given type, piston-speed, and speed of rotation, there existed a certain maximum stroke-volume per cylinder, and consequently a certain maximum horse-power per cylinder; from which it also followed that if the weight available for machinery was very limited, as in small craft of high power, the

Engineer-
Lieut. Sillince.

Engineer-
Lieut. Sillince.

solution seemed to lie in high speeds of rotation, and consequently a considerable number of cylinders; whilst for those cases in which the weight was not so limited, a longer stroke, a lower speed of rotation, and a smaller number of cylinders, would be permissible. It was probable that double-acting tandem engines, except possibly in large vessels for the merchant service, would be found prohibitive on the score of head-room required and the consequent inadequate protection, apart from the difficulty of arranging the valves and their operating-gear. The effect of the inertia of the reciprocating part at high speeds of rotation, especially if pistons and piston-rods were water-cooled, would be considerable, but in a double-acting cylinder working on a two-stroke cycle, or in a double-acting tandem engine operating on either a two- or a four-stroke cycle, the compression could be made use of to reduce inertia-effects. The most promising solution of the vibration difficulty appeared to lie in a six-cylinder, six-crank arrangement, or multiples thereof, particularly as that arrangement, in addition to being perfectly balanced, gave a fairly equable turning moment with an entire absence of dead points in starting or reversing. The two-stroke-cycle engine offered many tempting advantages for marine purposes, especially with regard to the simplicity of the valve-gear and of the reversing mechanism, and the economy of space. In large sizes, however, the difficulties connected with the dissipation of heat were serious, though there was every prospect of those difficulties being overcome in the near future. Oil-engines using heavy oil and working on the Otto cycle had been made reliably reversible in sizes up to about 80 B.H.P. In the case he was citing, the engine, although not outside those limits to which a reversing propeller or a reversing gear would apply, had been made with the object of demonstrating the possibility of making a reliable reversing oil-engine, and the object of the experiment had been achieved. There was no reason to suppose that 80 B.H.P. was by any means a limit. At present the power per cylinder in the oil-engine was small as compared with that of large gas-engines. The largest oil-engine he was aware of worked on the Otto cycle, single-acting, and developed between 180 and 200 H.P. per cylinder. The prospects of the internal-combustion engine for marine purposes were distinctly promising, but especially so in smaller sizes and up to 1,000 H.P. per shaft. A number of internal-combustion engines were either fitted on board certain ships of the Navy or nearing completion at the makers' works, for the purpose of generating electricity, whereby it was hoped the work of the boilers, especially in harbour, would be relieved to a considerable extent; and also others were used for the propulsion of service boats.

Dr. H. S. HELE-SHAW observed that the major portion of the Paper was devoted to a discussion of the variation possible in the well-known four-cycle gas-engine, especially in its application to marine purposes. No one would deny that that was a very interesting subject, but considering the wide range indicated by the title of the Paper, he ventured to think that some of the points which were either ignored or passed over cursorily were as important as, if not more important than, those to which the Author had devoted special attention. If instead of "large engine" the Author had used the words "large power," there was an altogether different variety of engines from those the Author had touched upon which might well be considered, and which, if they became large enough for application to large ships, would revolutionize the engine-room even more than the application of the turbine had done. He had in mind a reversing engine of 360 HP.; he took that particular engine merely because it was reversing, not because there were not many other engines now working of even higher power. He referred to the Antoinette engine, which had proved to be very practicable, and had given no trouble whatever, although it had twenty-four cylinders. A smaller engine built on the same plan as the Antoinette engine was before the meeting. Although it developed 35 HP. it could be lifted with one hand. It was not quite complete, but it lacked only the accumulators, and if magneto-ignition were used the weight of the accumulators could be dispensed with. That engine weighed 88 lbs.

Sir WILLIAM WHITE, K.C.B., Past-President, inquired the number of revolutions.

Sir William White.

Dr. HELE-SHAW replied that the speed was high—1,800 revolutions per minute. The Antoinette engine of 360 HP. weighed 1,500 lbs., plus 160 lbs. for the accessories, which worked out at $4\frac{1}{2}$ lbs. per horsepower. It had important advantages: there was no fly-wheel, and because there were so many cylinders, the engine was reversible. The reversing action was quite easy. The cam which regulated the valves was easily operated by a little machine and a mere touch was sufficient to reverse. The engine had of course to be allowed to stop before the operation for reversing was performed, but a well-made cylinder retained its charge ready to fire when the sparks were put on again.

Dr. Hele-Shaw.

Sir WILLIAM WHITE asked what was the interval of time.

Sir William White.

Dr. HELE-SHAW said the reversal was almost instantaneous. The spark was cut off, leaving the compression on, and the engine stopped instantly, then it was reversed, and it was on again before it was possible to see what had happened. The engine he exhibited

Dr. Hele-Shaw.

Dr. Hele-Shaw. had been made for a flying-machine. Referring to the Beardmore engine (p. 114), it would be found that a 500-HP. producer-gas engine for marine purposes weighed 45 tons for the engine and 20 tons for the producer, a total weight of 65 tons for the plant, the weight per horse-power being 280 lbs., or about sixty times as much as in the Antoinette engine. But the latter engine possessed a further advantage. The Author very properly made a strong point of the fact that it was difficult to reduce the power in gas-engines in the same way as in the steam-engine, by cutting off. With twenty-four cylinders, or any large number of cylinders, it was quite easy to have an arrangement for raising the exhaust-valves of any required number of cylinders, thereby putting them out of action at once and reducing the power in any desired degree. But, on the other hand, there were serious difficulties. Using petrol fuel it cost ten to twenty times as much to run the Antoinette engine as to run an ordinary steam-engine; but there were many internal-combustion engines working on petroleum, the price of which was less than half that of petrol and might be further reduced if the fuel were purchased in bulk. Although in England the cost would undoubtedly be prohibitive in comparison with coal, it was not so in many other places. Liquid fuel was actually cheaper, for instance, on the Pacific coast, in Russia, and so on, and it was obviously possible to build ships for many other places besides Great Britain. Still, the fuel question was a serious one. Engines had been working for years with petroleum, and as long as they had constant work they worked well. It was much more difficult in a motor-car, because the conditions were so variable; the temperature-changes, the variations of speed, and the objectionable smell, which under proper conditions at sea was not noticed, were very marked in connection with the motor-car. There were also other objections to such small high-power engines. First there was the multiplication of parts. In actual working, the engine, as far as certainty of action was concerned, left nothing to be desired. Formerly it had been very different, but to-day an engine would run in long-distance trials 5,000 miles without stopping, which proved the possibility of getting certainty of action in spite of the multiplicity of cylinders. The initial cost of the first engine was high, but it was well known that the cost rapidly diminished as an engine developed. Although he had shown the reversing engine, he did not hold that a reversing engine was necessary, and there he joined issue with the Author. The Admiralty were even harder to deal with than Lloyd's in the matter of getting things passed, yet they had passed in the "Dreadnought"

the principle of reversing gears—gears which reversed with a clutch —as being quite satisfactory in their action and quite safe. The modern high-tensile nickel-chrome steel allowed wheels to be made which contravened all text-book rules. In motor-car practice he had seen wheels, which had worked at many times the stress allowable in theory, apparently as good as new after running 30,000 miles. Therefore he did not see why engines of that type should not be coupled up in batteries to propel ships. Turbines had led the way in the matter of multiplication of shafts. He saw no reason why such an engine should not develop much larger powers than those which the Author had mentioned as at present in use in internal-combustion engines. If there was any doubt in applying the Author's reasoning from a small scale to a large scale, he would ask the members to remember what was said when the "Turbinia" made her marvellous run at Spithead between two lines of battleships: "A small boat like that is all very well, but it can never be applied on a large scale." He believed that was the moral to be applied to the little engine he had shown that evening. In conclusion he wished to express his thanks to the Adams Manufacturing Company for the loan of the engine.

Mr. H. C. ANSTEY remarked that no doubt great advances had been made in regard to the possibility of gearing for reversing, but there was one consideration which limited it. Although by the aid of gearing the necessity for running the engine in either direction could be obviated, yet it did necessitate coupling and uncoupling the engine from the propeller-shaft, and that meant some form of clutch. In order to transmit a reasonable amount of power per revolution it would be necessary to have a fairly large diameter, and as the centre-line of the shaft must be somewhere below the water-line, it was impossible to get more than a certain diameter of friction-clutch, and that would limit the amount of power that could be transmitted per revolution, although it might be admitted that things were done now by clutches and gearing which were not dreamt of some years ago. The Author laid down as an axiom that the engine must be reversible, and Mr. Anstey was able that evening to give, by permission of the Admiralty, a description of the reversible engine which had been alluded to by Lieut. Sillince. The engine was a four-cylinder vertical engine of the enclosed type, developing 80 B.H.P. The four cranks were arranged as two pairs, each one of a pair being opposite the other, and the plane of one pair being at right angles to the plane of the other pair. The cranks as seen in end view were thus 90° apart. That arrangement, while not giving the best turning-moment, had been adopted for facilitating

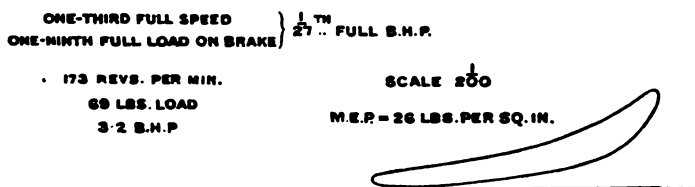
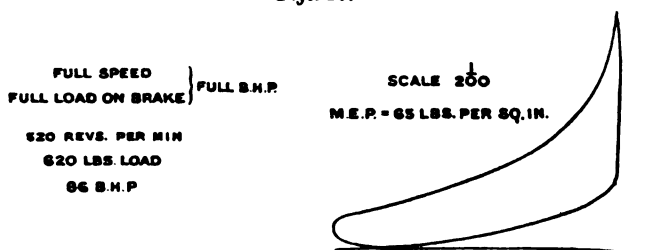
Dr. Hele-Shaw.

Mr. Anstey.

Mr. Anstey. starting and reversing. The engine in normal running, either ahead or astern, worked on the usual four-stroke cycle, each cylinder having the same cycle of working as the ordinary Hornsby engine as applied to other purposes. There were separate sets of cams for both ahead and astern, the cam-shafts being capable of motion end-ways to bring either set into action. In addition, there were the cams necessary for actuating the air starting-valves and fuel oil-pumps. Starting in either direction was effected by compressed air, which operated on three cylinders only, giving each cylinder a working stroke every revolution. The remaining cylinder was always on the normal working cycle. The cycle of operations was then the following. Supposing the engine was stationary when an order was received to go ahead, the first motion would be to put the starting-lever into position for starting ahead. Compressed air was then admitted in turn to cylinders 2, 3 and 4, and the shaft began to move in the required direction. The crank of cylinder No. 1 was carried round, and at the end of its first compression-stroke after starting, it received an impulse due to its own charge of air and oil. The next motion was to put the starting-handle into the position for working ahead, the effect of which was to change cylinders Nos. 2, 3 and 4 from their two-stroke cycle, using compressed air, to their ordinary working four-stroke cycle. No. 1 cylinder remained at work unchanged by that operation and kept the engines running, while cylinders Nos. 2, 3 and 4 in turn picked up their ignition at the end of their first compression-stroke after the cams had been put into their working position. An exactly similar series of operations took place when going astern, the cam being arranged suitably for each direction of rotation. In order to provide for possible stopping of the engine on a dead centre, cylinder No. 1 had also a hand-worked starting-valve, which gave a separate charge of compressed air sufficient to move the crank away from the dead point. Compressed air was supplied by a small single-cylinder auxiliary engine of about 4 B.H.P. direct coupled to a Reavell compressor, which discharged into a receiver of sufficient capacity to provide for about eight reversals with the auxiliary engine stopped. With the engine going ahead and astern as quickly as was likely to be required in any emergency, the auxiliary engine and compressor was sufficient to maintain the full air-pressure in the reservoir. The maximum time required to go from full speed ahead to full speed astern was found to be 10 seconds, the time being taken from the giving of the order to the moment the engine was well started. The average time of several trials was $7\frac{1}{2}$ seconds. That engine worked satisfactorily, but of course it was only 80 B.H.P., and it was

a far cry from 80 HP. to 1,000 HP. The first question was: Why was Mr. Anstey there a difficulty about reversing? The ordinary standard engine of commerce—the engine that a maker sold like a pound of sugar—would run in either direction. What, then, was the difficulty? He thought it was summed up in two things—perfection of detail and reliability of ignition. The system might be the best in the world, but if there were defects in some points of detail, if some things were overlooked, the whole thing would be a failure. With regard to reliability of ignition, when the engine was started by the motive power, whatever it was, it was necessary to make absolutely certain that the cylinders did pick up the ignition at the proper time and so carry on the work which had been initiated by the starting-devices.

Figs. 10.



The engine he had described fulfilled the Author's conditions (a) and (b); it was also capable of running at reduced speed. The full speed was about 500 revolutions per minute, and it had been at speeds between 140 and 160 revolutions per minute in the boat without stopping. He had not any diagrams from that engine, but *Figs. 10* were from a similar engine. It would be seen that the full-load card showed a mean pressure of 65 lbs. per square inch. Running the engine on a brake load at one-third speed, carrying one-ninth of full load, that was to say, one twenty-seventh of the full brake horsepower corresponding with what the engine would do in the boat at this reduced speed, the mean pressure was 26 lbs. per square inch: the mean pressure at reduced speed was therefore 40 per cent

Mr. Anstey. of the mean pressure at full speed. According to the Author's calculation it should have been possible only to reduce the speed to 63 per cent. of the full speed. He was somewhat surprised at the Author's figures, because he knew his reasoning was sound; but he thought there were two points the Author had not taken into consideration. The engine he had described had a fly-wheel, but a very small one—on a land engine it would be called ridiculously small—and the turning-moment was certainly not good, due to the arrangement of cranks adopted for starting and reversing. The two points were as follows. First of all, the resistance of a ship varied as the square of the speed, and therefore it was the effective power at the propeller which varied as the cube of the speed, and it was the mean pressure corresponding with the effective power which should vary as the square of the speed. It was customary in connection with steam-engines to consider that the effective power and the indicated power were more or less in a constant ratio, and no doubt that was approximately correct; but in an internal-combustion engine, as the load was reduced he thought it probable that the mechanical efficiency fell off, and consequently there was at reduced speeds a higher mean pressure than would be expected from the effective power which was being transmitted. The second point was that when the boat was under way there was a considerable stream of water flowing past the propeller, and that tended to keep it revolving, even though the turning effort momentarily fell off. He quite admitted that that was not a thing to be relied upon, because in a seaway, if the vessel were hove to, the sea would probably be striking the propeller, and, with an inadequate turning-moment, the engine might be brought up all standing: therefore it was very necessary and desirable to secure an even turning-moment. He agreed with Lieut. Sillince that a six-cylinder single-acting engine would be most likely to give the best results. The Author had given an idea of what power was possible in a gas-engine, and Mr. Anstey would like to mention what was possible in a large oil-engine. In the development from 80 to 1,000 B.H.P. many details would have to be worked out—details which would be quite different in the large engines from what they were in the smaller ones. The largest power yet attempted in a single cylinder was about 160 to 200 B.H.P., and he believed there were only two types of oil-engine in which this had been achieved, the Hornsby, which he had described, and the Diesel. Six of those cylinders would give about 1,000 H.P., and if the ship was a twin-screw ship 2,000 B.H.P. would be obtained, which would give a ship of about 5,000 tons or 6,000 tons displacement a speed of 12 knots. The space required would be an

engine-room about 33 feet long and 26 feet wide, with head-room of Mr. Anstey. probably 15 feet or 16 feet from the centre-line of the shaft. Of course, such an engine would take some time to work out. There were two factors, time and cost; but he had no doubt that some time or other a start would be made on those lines, and an engine would be produced which would be a success in every respect.

Mr. R. W. A. BREWER considered that the most important point in Mr. Brewer. the problem was the production of an explosive mixture. The solution of the problem of generation of power when that mixture was produced was very far advanced, but the question of the fuel to be used for marine purposes still required considerable study. He could see only one solution at the present time, and that was the adoption of a heavy oil—the residuals left after the lighter fractions had been distilled off. The heavy oil should be what was left after about 350° F. had been attained in the distillation process. With regard to the quantity of that kind of fuel available, he had figures which showed that the production from the world's oil-fields in 1906 amounted to about 30 million tons of crude oil. Under the present standard only about 1 million tons were distilled off at a temperature below about 212° F., and if that standard were altered, as it was hoped it would be within a measurable time, the total quantity of the lighter residuals which would be distilled off would only amount to about 3 million or 4 million tons per annum. The heavy residual oil would be in no way dangerous when used on board ship. Every other system that had been proposed—gas-producers and so on—was attended with serious risk on board ship, in addition, of course, to the weight which such parts of the machinery must necessarily have. The advantages of storage and manipulation attending the use of liquid fuel were well known, but with internal-combustion engines there were many other considerations. Up to the present, the great disadvantage of the use of liquid fuel had been the extreme difficulty of measuring exactly the small charges that were necessary for use in an internal-combustion engine. It might be taken that the system of measuring exactly each individual charge was the only system that could possibly succeed when used on that scale. The conditions which obtained in a small engine did not obtain to the same extent in a large engine, because the amount of oil required per charge was considerably greater; the measuring apparatus could therefore be more crude, and any wear of the working parts would not affect the result in the cylinder so much as it had done in using the same system on a smaller scale. He did not see any great difficulty in designing and producing a large

Mr. Brewer. oil-engine; and from the figures he had given he felt sure that a large supply of fuel was available. A previous speaker had doubted that, but the figures Mr. Brewer had received from a very reliable source showed there could be no doubt as to the supply of that fuel. There was also another important thing from the point of view of the motorist. At present people using liquid fuel were largely in the hands of the controllers of the supply. The chief reason for the handicap in that direction was the distillers' difficulty in getting rid of the residuals. By opening up an extensive market for heavy residual oil, some co-operation could easily be arranged between users of products of petroleum in every form, and that point alone was important. The supply of liquid fuel would be controlled to a very large extent, and the price of the fuel would be fixed. For that reason alone the use of liquid fuel should receive careful consideration at the hands of those who were engaged in the design of large internal-combustion engines.

Sir William
White.

Sir WILLIAM WHITE, K.C.B., Past-President, observed that the discussion so far had been in the hands of those who had to do with the designing or working of the machinery, but what he wished to say would be from the point of view of the men who had to design and build the ships in which the engines had to work. It was well known that he was among those who looked upon the extended use of the internal-combustion engine for marine purposes as not merely a probability but as a thing which, starting perhaps on a small scale, must grow. To what extent it would grow, no one could quite foresee at present; but considering the comparatively limited time the application of the internal-combustion engine had been proceeding, remarkable progress had already been made, and much information had been obtained as to the best lines of advance. In his Presidential Address 3 years ago he gave certain facts as to what had been done in the way of applying internal-combustion engines to the propulsion of small vessels;¹ but since that time much more had been done, not merely in the scale of operations but in the variety of the experiments made. The general impression made on his mind by the remarks in the discussion, especially those of Mr. Dugald Clerk and Professor Burstall, was that in the application of internal-combustion engines to the propulsion of ships there would be many difficulties on the large scale which had not been of serious importance hitherto; and that those highly experienced men did not look forward with confidence to the immediate advance of the internal-combustion engine to large powers for marine purposes.

¹ Minutes of Proceedings Inst. C.E., vol. clv, p. 42.

That opinion was an important one; but he had gathered in subsequent conversation that Mr. Clerk did not mean to convey the idea that the difficulties to be faced were insurmountable; and that was a very important fact. To the conditions which the Author had stated (from the point of view of a marine engineer) as necessary to be fulfilled in a successful marine engine, he would like, as a naval architect, to add two or three others, which in the practical application of the internal-combustion engine to ship-propulsion would have a very important bearing upon success or failure. For example, there was the question of safety when such engines were fitted in the confined spaces that were unavoidable in the engine-rooms of ships. It was said that there ought not to be leakages, that there ought not to be formation of explosive mixtures—in fact, there ought not to be anything to conduce to accidents; but as long as machinery was not absolutely perfect, and as long as the human element was not always consistent or efficient, he presumed that conditions which might tend to accident would exist, and undoubtedly would have to be guarded against. It seemed to him that, in any application of the internal-combustion engine in a confined space, it should be of the essence of the design that with ordinary care and management there should be no accumulation of gas such as could possibly form an explosive mixture. Reference had been made in the discussion to the question of the rate of rotation, and the questions he had put to Dr. Hele-Shaw with regard to the beautiful little engine he had exhibited had been asked advisedly, because power was not put into ships simply to show the triumph of the mechanical and marine engineer, but was put there to propel the ship economically and efficiently. An engine working at a very high rate of revolution and giving a very poor efficiency of propulsion would be highly unsatisfactory to the shipowner, or to the person who had to design the ship. Sometimes there was a tendency to separate the question of the efficiency of the motor from efficiency of propulsion, which included, of course, the efficiency of the propeller.

Sir William White.

Professor HELE-SHAW said he had meant working through gearing.

Professor Hele-Shaw.

Sir WILLIAM WHITE remarked he was very familiar with the processes of reduction that were contemplated. The rate of revolution, however, had such an enormous effect upon weight and space that it must of course be taken into account. Many things might be done in a small vessel that could not be done in a large ship; many things might be done in an open space that could not be done in a confined space; and many things that could be done with perfect propriety in a

Sir William White.

Sir William
White.

motor-car could never be done in a ship. As to what could be done in a flying-machine he spoke with no authority at all. When a man embarked on such an enterprise, the small details of the efficiency of an engine or the escape of a little gas hardly counted. Those were points which were of great importance in the application of internal-combustion engines for marine purposes. Of course space and weight, and weight of fuel for a given voyage, were matters which the ship-designer had to put in the forefront of his work. In all that had been said in the discussion he had not been able to gather any specific information whatever on any of those points. It might be that the information did not exist. Perhaps it was asking too much at present to require particulars of internal-combustion engines of large power such as would be used in ships. The question of the practical application of gas-engines of large power to ship-propulsion could not possibly be dealt with at the present time; and he was sure the Author would agree with him in that. He was quite aware that before that information could be given to the ship-designer experiments must be made on many machines in order to obtain data that would be a guide for the estimates given by the marine and mechanical engineer to the naval architect. Of course there were in the world people who did not feel that difficulty. Two years ago he studied with great interest, but not with that conviction which the writer intended to produce, a design for twin-screw gas-engines aggregating 10,000 HP. The writer of that article produced an elaborate drawing showing the design of the engine in detail, and gave an estimate of weight and an estimate of its rate of fuel-consumption. It was a producer gas-plant, and he gave everything that could be desired; indeed, he was prepared to go to the second place of decimals! But the article did not carry to Sir William White's mind the conviction which would be necessary before he put his name to a design embodying that machinery. No doubt the inventor was quite convinced that it could be done; but, knowing what he did of the largest gas-engines produced up to that time, all Sir William could say was that the inventor had the courage of his opinions, but was certainly not likely to get many customers to purchase the engines which he was so ready to design. It seemed to the speaker, notwithstanding what had been said by Mr. Brewer respecting the use of oil for marine purposes, that the question of internal-combustion engines came back to the question of the use of producer-gas. It had been said that the residuals left after the distillation of oil were difficult to get rid of. Speaking from personal knowledge, he could say that, when an attempt was made to put into the form of a binding contract any arrangement

for the purchase of such residuals for fuel there was the greatest difficulty. High authorities—perhaps as high as any the last speaker had quoted from—had told him in the course of general conversation that there was no difficulty whatever in guaranteeing almost unlimited supplies at very moderate prices; but those same high authorities, when it became a matter of contract extending over a definite time at a fixed rate, were not ready to commit themselves. He thought it would be found, if the matter was looked into, that the position was still very much what it was about 12 or 14 years ago, when the Italian Government—which had no preference whatever for coal over oil as a fuel, because Italy produced neither—having sent a most capable commissioner to study the matter on the spot in the oil-producing regions of Russia and America—came to the conclusion that the visible supplies of the residual products of distillation of petroleum were altogether inadequate for the supply of fuel for marine purposes, even for the trade of the Mediterranean. Since that time there had been a large increase in the production and in the uses of petroleum; and he was convinced, after close study of the subject, that it was not possible to depend, under commercial conditions, upon the visible supplies of residual products of petroleum distillation either for fuel or for extensive use in oil-engines of the mercantile marine—or even a small fraction of the mercantile marine—of the world. No doubt it was perfectly true that, as an auxiliary to coal, oil was of the greatest value. The Italians had proved that long ago: they had threshed the thing out completely by their own trials, and they had rested upon the conclusion that oil must be looked upon as an auxiliary, and not as a substitute for coal. If that was true, then it was not possible to consider the question of the use of the internal-combustion engine in ships on a large scale without having resort to producer-gas. That was his own feeling at the present time. He did not say it was always going to be true; but if there was to be any large application of gas-engines on board ship under existing conditions, it seemed to him it would have to depend mainly on producer-gas. Therefore, if the matter was to be taken up in a practical fashion on a large scale, the perfecting of the gas-producer, to which Lieut. Sillince had alluded, and which was already in hand, would lie at the very foundation of any great or general progress. Of course that would mean gradual experiment and gradual development, and that was of the essence of the problem. No one would be wise to make a great step without assuring himself of reasonable prospects of success. Dr. Hele-Shaw had spoken of the “Turbinia” and her performances, of what was said about them at the time, and of what

Sir William
White.

Sir William
White.

had since happened. That was perfectly true; but while it was true in principle, there were many conditions in which the parallel did not hold; and he thought Dr. Hele-Shaw would agree that that was so. He himself was all for progress, but he was also convinced that it was necessary to proceed with care; and he was of opinion that the best results would be obtained when it was possible to get those who had had extensive experience in the construction of gas-engines or internal-combustion engines for other purposes to work with marine engineers in attempting to carry to a successful issue that particular application of the internal-combustion engine which had been under discussion.

Mr. May. Mr. JOHN MAY observed that, although he was not a marine engineer and knew little about gas-engines, he had been struck by the conditions that were set down in the Paper as necessary for a successful marine engine. The speakers at the opening of the discussion had shown how imperfectly the gas-engine was adapted to meet those conditions, but in all probability they had been drawn up having regard to the present practice with steam-engines, and on the assumption that there must be a direct drive from the engine to the propeller. Some little time ago a similar problem was attacked in Russia. As the result there were at the present time two boats on the Volga driven by oil-engines; but the propellers were driven through electromotors and not directly. A little thought would show at once what a wonderful revolution that would make. If it were possible to introduce electric driving, all the difficulties would disappear. First of all the starting, stopping, and reversing would be perfectly controlled. Then the number of engines could be varied; instead of having the monsters so many people were nervous about, it was possible to have as many smaller engines as were necessary and to put them in any part of the ship. There was further no need to run the gas-producers in parallel; a separate producer could be used for each engine. Altogether, the electrical combination would be almost an ideal combination, except for the extra weight and the small loss in transformation. It seemed that the advantages of the electrical drive were so great, and dove-tailed into the gas-engine problem so perfectly, that it ought to be considered whether it would not be feasible to adopt the electric drive in spite of its drawbacks. Another point arose with regard to water. On land gas-producers used a great deal of water, and he would like to ask whether salt water would be an acceptable substitute for the water used for cooling the engines and for the scrubbers. Suction gas-producers needed about 2 gallons of water per brake horse-power-

hour, and it would be impossible to get that at sea except by using Mr. May. salt water. He also wished to know the amount of fresh water necessary for the producers. Even if salt water could be partially used it could not be used for all purposes. With reference to Mond gas, his only experience had been a very unhappy one. It occurred in connection with a producer for which it was claimed that no elaborate washing-appliances were necessary. The producer was put up and the engine had not been running more than a few hours when the valves were taken out with a beautiful glossy surface as though they had been japanned. The Mond producer owed its success largely to the ammonia-recovery process, the gas receiving such thorough treatment in going through that it came out clean; but when the gas was taken straight from the producer there was trouble at once, to judge from his experience.

Mr. ALEX. SIEMENS called the last speaker's attention to the fact Mr. Siemens that to drive ships by electricity would necessitate first having a gas-plant powerful enough to drive the ship, then an electric generating-plant strong enough to drive the ship, and then electric motors sufficiently powerful to drive the ship. The weight would render it absolutely impossible to drive a ship by electricity in that way.

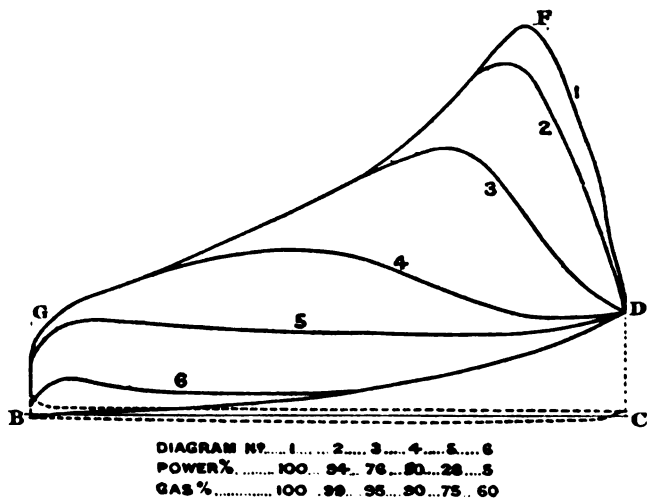
Mr. MAY pointed out that a much higher speed of revolution could Mr. May. be used for the engines.

Mr. SIEMENS maintained that he was right. He had studied the Mr. Siemens. matter thoroughly in connection with a Paper on the subject which he had read before the British Association at Dover.

Mr. W. W. TONKIN remarked that many years ago he had a great Mr. Tonkin. deal of experience with gas-engines, working with the two-stroke cycle of the kind described by the Author at p. 125. This engine had one single-acting cylinder, the explosion taking place only at the back end of the cylinder, the front being closed and used for compressing pure air into a reservoir. The coal-gas was compressed separately, and the gas and air were mixed in the valve as they passed into the cylinder for a certain portion of the stroke, and then cut off, ignited, and expanded during the rest of the forward stroke, and the whole exhausted during the return stroke. The cycle was similar to the Author's proposed cycle. With this engine it had always been found possible to start, even with half load on, by opening the stop-valve and admitting the compressed air left in the reservoir from the previous day's work, the engine being relieved of the work of compression for a few strokes by tripping the air suction-valve. With a number of cylinders, starting would be still easier. There were, however, other important advantages of this proposed two-cycle gas-engine, which had not been mentioned by the Author. Chief

Mr. Tonkin. among these was the possibility of varying the power of the explosion to any extent, promptly and economically. Referring to *Fig. 7* (p. 122), theoretically the rise of initial pressure from D to F, as also the work done during the subsequent adiabatic expansion from that pressure, should be in exact proportion to the amount of heat supplied, the efficiency remaining the same for all initial pressures and powers; but when the heat was obtained from an explosive mixture there were narrow limits below which the mixture burned too slowly, or failed to ignite at all. He had placed some diagrams on the wall, of which *Fig. 11*, taken from an old four-stroke gas-engine many years ago, showed the effect of weakening the gas mixture by varying the period of gas-admission from full stroke down to 60 per cent. of the stroke by a cam with six steps. *Fig. 11* showed that the power was

Fig. 11.



varied fairly well, but the economy was very low. On cam 5, admitting gas for 75 per cent. of the stroke, only 28 per cent. of the full power was obtained; while on the lowest gas-admission of 60 per cent. (cam 6) only a small explosion was shown towards the end of the stroke, and the gas burning during exhaust always fired the next charge. This method of varying the dilution of the charge was still in use in large gas-engines, in cases where steady driving was of more importance than economy; but it seemed to him that any arrangement of this sort was unsuitable for marine purposes. In order, therefore, to make use of the theoretically perfect method before referred to, of governing gas-engines, it was evident that

some means must be found of introducing into the cylinder varying quantities of gas-mixture of constant strength, and kept separate from the rest of the contents of the cylinder. After many experiments in glass cylinders, with smoke to represent gas-mixture, he

Fig. 12.

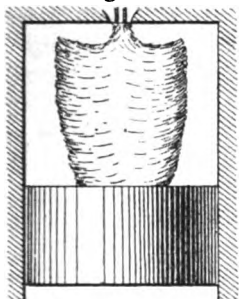
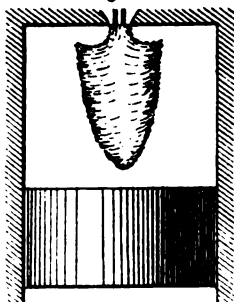


Fig. 12a



had been able to get the results sketched in *Fig. 12*. Pure air entered by a port next the inner wall of the cylinder, and the smoke by a port in the centre, forming a central core of the shape sketched, the size of which could be varied by throttling the centre port. *Fig. 12a* represented the smoke-cone when only a small quantity

Fig. 13.

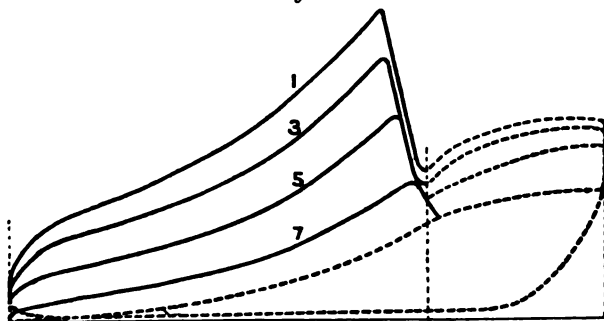


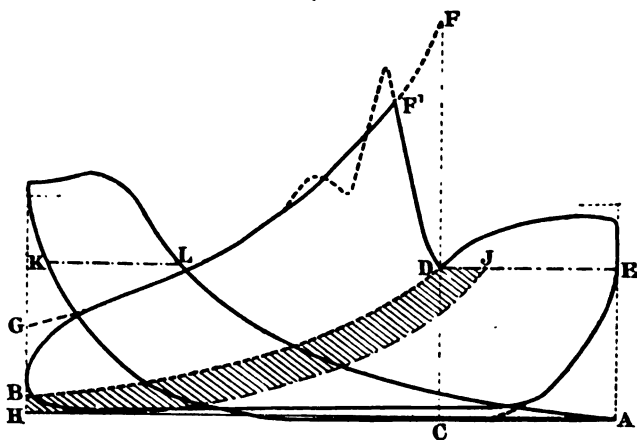
DIAGRAM NO. 1.....3.....5.....7
POWER %.....100...78...52...27
GAS %.....100...83...54...28

passed in, the rest of the cylinder being filled with air. When applied to a gas-engine cylinder, this arrangement was completely successful, it being found possible to vary the power of the explosion to any extent and in any direction.

Fig. 13

Mr. Tonkin, showed four superposed diagrams taken from this engine at different powers illustrating the effect of varying gas-supply, and in all cases the ignition was prompt, only the height, and therefore the power, varying with the gas supplied. The amount of gas-mixture in the centre was varied by a throttle-valve, the rest of the cylinder being filled with air under compression. *Fig. 14* showed the complete full-power diagram No. 1, the compression-curve being shown on the left, and the admission and explosion on the right hand. In comparing *Fig. 14* with the four-stroke-engine diagrams shown in *Fig. 11*, it was only necessary to take the explosion portion of the former diagram, measured from the top expansion-curve FG, *Fig. 14*, down to the expansion-curve DB,

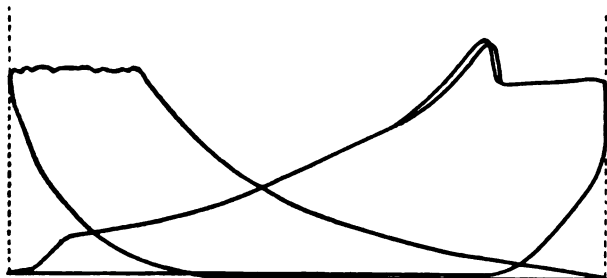
Fig. 14.



which would be drawn if there had been no explosion. Working out in this way the power of the explosion for the four diagrams shown in *Fig. 13*, and calling the power and gas-consumption for No. 1 diagram 100 per cent., then diagram No. 3 gave 78 per cent. of the power with 83 per cent. of gas; diagram No. 5 gave 52 per cent. of power from 54 per cent. of gas; and diagram No. 7 gave 27 per cent. of power from 28 per cent. of gas. The power was thus practically in proportion to the gas-supply within the limits of experimental error. The amount of gas required for a given power in this explosion-curve DFG B was found to be practically the same as for ordinary four-stroke engines; it depended on the ratio of expansion, and varied in the same proportion as in present gas-engines with hit-and-miss regulation. Another

advantage of the Author's proposed cycle was that it was possible to use a regenerator in the port leading into the cylinder, as in the case of a hot-air engine, and thus to obtain a considerable amount of extra power from the heat of the exhaust, which would otherwise be thrown away. The effect of heating the compressed air as it entered was to lessen the quantity drawn from the reservoir—the pressure in which therefore rose until a balance was obtained from the reduced volume discharged by the compression-pump at the higher pressure. This was shown in *Fig. 14*, where KL was the volume discharged, equal to EJ, which by heating was caused to expand and fill the volume ED. In *Fig. 14* the shaded portion JDBH showed the amount of power in this diagram gained from the action of the regenerator: the lower curve JH of the shaded part was the curve of compression, and the line DB the curve of expansion of the heated mixture without explosion, and the difference

Fig. 15.

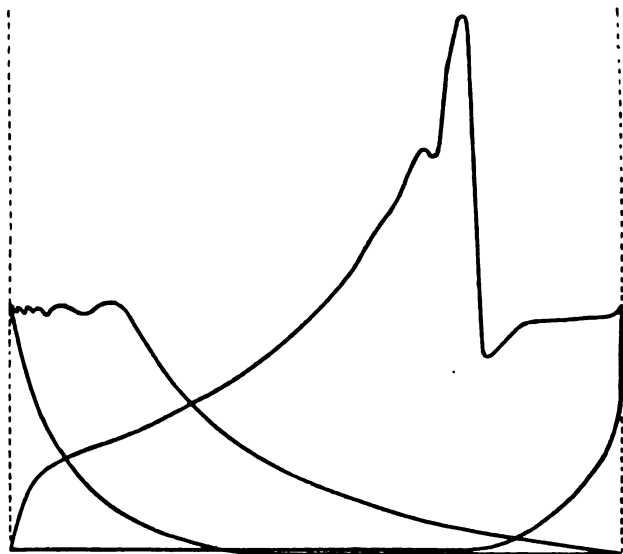


was due entirely to the regenerator. In diagram No. 1, shown in *Fig. 14*, the power of the explosion-area, FGDB, was 5 HP. at 160 revolutions; the shaded portion below gave 1.6 HP., equivalent to a gain of 32 per cent. extra power from the same quantity of gas. Even after allowing for the excessive losses in this engine due to small ports and for the usual suction and exhaust losses, the net power of the whole diagram was 6 HP., showing a gain of 20 per cent. from the action of the regenerator over the ordinary power derived only from the explosion. The heating action of the regenerator was specially useful when using paraffin oil or poor gases. This kind of engine was therefore specially suitable for any case where it was necessary to reverse and go at different speeds. He had had the engine running unloaded at 36 revolutions per minute for an hour (*Fig. 15*), also at full power at 85 revolutions (*Fig. 16*), and it could be started and controlled at all powers

Mr. Tonkin. exactly the same as a steam-engine, and without a governor. He therefore agreed with the Author in thinking the time had come to reconsider the question whether it is not advisable to adopt a more suitable cycle for gas-engines than the present four-stroke cycle, to enable the gas-engine to compete with the steam-engine on more equal terms.

The Author. The AUTHOR, in reply, regretted that more had not been said from the marine engineer's point of view. Sir William White had justly said that in order to make progress in such a new departure it was necessary to get together the gas-engineers, or those who had

Fig. 16.



been used to internal-combustion engines and knew their peculiarities, and the marine engineers, who knew all the requirements for marine engines. Fortunately some of the gas-engineers had spoken, and they seemed to be under a similar impression; they said it would be desirable to know what a steam-engineer thought of a gas-engine. Sir William White had spoken as though it were contemplated in the near future that internal-combustion engines would be used in all ships, but he did not think that was ever contemplated.

Sir William White. Sir WILLIAM WHITE did not think he had said anything to suggest that.

The AUTHOR observed that there certainly were places where oil The Author. was a much cheaper fuel than coal, and in such places, if ships were wanted, it appeared to him that, instead of burning the oil in a steam-boiler and using its energy through the medium of the steam-engine, there would be a great field for an oil-engine pure and simple. That would save many things. First of all, there was no boiler to deal with. Mr. Anstey had mentioned that the space required for an oil-engine of 2,000 B.H.P. would be much less than the room occupied by an ordinary marine engine of the same power, let alone the boiler-space; and besides that there was a saving of bunker-space. If coal was used, it was necessary to carry coal for the whole of a voyage. Using oil as a fuel, even if there were no great advantage in the weight to be carried—which there was, even in using it as a fuel in boilers—a good deal of stowage-capacity would be saved, because oil could be put where coal could not. It must therefore be admitted that there were many places in which oil was being used as a boiler-fuel, where, if an internal-combustion oil-engine could be used, it would be of great advantage. Professor Burstall was perhaps rather severe. He seemed to think that it was not possible to make a large vertical internal-combustion engine. He did not say, however, why the vertical engine could not be employed. As a matter of fact, vertical gas-engines had been used very successfully in many places, although perhaps not of so large a size as some of the large horizontal engines. After all, he did not think the question of vertical or horizontal should come into serious consideration, for if a horizontal engine was practicable, and a vertical one was not practicable, it was only necessary to look back for a few years to find horizontal engines on board ship and working very successfully. The vertical steam-engine had come into general use on ships because as a whole it was a better engine than the horizontal, but it was not essential that marine engines should be vertical. Again, Professor Burstall and others seemed to be wedded to the four-stroke cycle, but the Author himself thought the two-stroke cycle was likely to meet the requirements of marine engineers very much better than the four-stroke, principally because it gave a greater range of adaptability of speed, and presented no difficulties whatever in reversing. The worst Professor Burstall had said about the two-stroke cycle was that it could not be so economical as the four-stroke. If the figures were correct that a four-stroke cycle engine was working on 0·7 lb. of common coal per indicated horse-power-hour, there was such a margin between this and the best marine practice with steam-engines, that even if another engine were made which had no mechanical difficulties, but which did not give quite so much efficiency as the four-stroke cycle,

The Author. it would be still a long way beyond the steam-engine. The strongest criticism of Mr. Dugald Clerk against the two-stroke cycle was that it was liable to back-fire. In the engine proposed there would be no question of back-firing, because the air and the gas would be compressed separately; and if an oil-engine were used instead of a gas-engine, there would of course be no question of back-firing. The question of safety had been raised by Sir William White, and the safety of the men working in the engine-room was of course a vital matter; but, in case of accident, his own impression was that an oil-engine was a safer engine to be alongside when it was breaking up than was a steam-engine. Because a four-stroke cycle was, on the whole, the best to be employed on land, it by no means followed that it would be better than the two-stroke cycle for marine work. The four-stroke-cycle engine required either a large number of cylinders or a large fly-wheel, and it also needed two-to-one gearing for its valves. Both fly-wheels and gearing were very undesirable in marine engines. The four-stroke cycle presented more difficulties than the other in the way of reversing, whilst the two-stroke-cycle engine permitted of the necessary variation in speed, which could not be obtained in the four-stroke-cycle without the employment of a larger number of cylinders than was really required for the maximum power. The multiplicity of cylinders advocated by Dr. Hele-Shaw was very undesirable at sea. Mr. Anstey had pointed out that the mechanical efficiency of an oil-engine fell off rapidly with the decrease of the load. This was no doubt due to the fact that the constant friction of the engine operated on all four strokes of the cycle, whereas the forward pressure operated only on one. In this respect, therefore, it would be expected that the two-stroke engine would not show such a falling off, and possibly also for the same reason the two-stroke engine would show a greater efficiency than the other at all powers. Professor Burstall feared that in a large cylinder with a two-stroke cycle the water-jacketing would not keep the cylinder-walls sufficiently cool. This was a matter to be determined by experience. In this respect it was worthy of notice that large Körting engines, which worked on a two-stroke cycle with separate air- and gas-compression, were still being made in Germany. It seemed, therefore, that the anticipated trouble did not exist. Condition (b), namely, that of prompt starting, had not received much attention in the discussion. Mr. Anstey had explained that, in his small four-cylinder four-stroke-cycle engine, he obtained complete command in this respect by having three out of the four cylinders actuated as two-stroke-cycle air-engines, leaving the other cylinder to act as an

internal-combustion engine. It was to be noted, however, that his The Author. engine had necessarily to be fitted with a fly-wheel, which was out of place in a large marine engine. In conclusion, the Author believed that, as stated in the Paper, the best solution of the problem of internal-combustion engines for marine purposes would be found to lie in the adoption of a two-stroke-cycle engine with three double-acting cylinders and three cranks, using separate air- and gas-compressors independently driven.

Correspondence.

Mr. A. C. HOLZAPFEL observed that the Paper suggested rather an Mr. Holzapfel. ideal engine, an engine which ultimately might be evolved out of a large amount of further practice, but the adaptation of which at the present moment would offer almost insuperable difficulties. As regarded his proposal for separate compression, this had been in use by the Messrs. Körting, of Hanover, for many years, but these engines were not successful : from what Mr. Holzapfel had learnt they had not in practice been so economical or so perfect as theorists had claimed for them ; so that when he visited the works of Messrs. Körting about 2 years ago he found that nearly all the engines they were then building were of the four-cycle type. From inquiries which he had made of many practical and scientific men, he had no doubt that the best engine to be adopted in the first place for marine work would be the four-cycle engine, and that it would be desirable to have a number of cylinders of comparatively small diameter, preferably about a dozen. It would be desirable to have these engines with cylinders mounted tandem fashion, that was, twelve cylinders with six cranks. Such engines, of course, would take up considerable space longitudinally, but this need not increase the amount of space now allotted in modern vessels for propelling purposes, as the gas-generators could be fitted at the sides of the engines. Personally he thought it would be best in the first engines to use only anthracite coal, although his firm had had in very successful use on land, for more than 2½ years, a 500-HP. Mason gas-plant using bituminous coal. He thought it would be risky to put in charge of steam-trained engineers, not only an engine but also a gas-generating plant of entirely new design ; in fact, this was essentially a case where two bites should be taken at the cherry. The Author did not refer to the work which had been done by Mr.

Mr. Holzapfel. Emil Capitaine in connection with the adaptation of gas-engines for marine purposes. Mr. John Thornycroft had referred to this in a Paper¹ read before the Institution of Naval Architects in March, 1906. Since that time the Capitaine Gas-Motor Company of Düsseldorf had built nine or ten sets of engines of the vertical type, ranging from 50 to 300 HP., which had been fitted on board tugs and cargo-vessels mostly running on the Rhine. In November last he was present at the trial trip of a tug at Düsseldorf so fitted. She had engines of 150 HP. with five cylinders of the four-cycle type, with a small fly-wheel running between cylinders Nos. 3 and 4. Like all the other vessels so fitted, she used anthracite coal and her suction-plant was of the most compact type. So far as he could judge, the vessel worked in every way satisfactorily, except that there was some slight difficulty in restarting the engines after once they had stopped. In none of the Capitaine types had any reversing arrangement been successfully carried out. The reversing so far was effected by a clutch. He considered it very desirable that similar engines should be fitted on small river and coastal craft in this country in order to get actual experience, as only by experience and slow evolution could this type of engine be successfully developed for use in large vessels. In conjunction with his brother, Mr. Max Holzapfel, he had tried for the last 2 years to obtain a practicable gas-engine of 500 or 600 HP. to fit on board a cargo-vessel, and which would be able to reverse and would otherwise answer the requirements for sea service; but so far they had been entirely unable to obtain such an engine, although several large firms had at first assured them that they could supply it. He did not think the Author's remark in regard to the high pressure of some gas-engines towards the end of the stroke expressed universal experience, for he had seen quite a number of diagrams where near the end of the stroke the pressure was less than atmospheric pressure. Particularly was this the case in the Diesel engine.

**Rear-Admiral
Melville.**

Rear-Admiral GEORGE W. MELVILLE, U.S. Navy, remarked that it must be felt by all marine engineers that a great advance was impending in the use of internal-combustion engines; the development had even now passed the initial stages. The field for such engines on land had long been recognized as enormous, and would greatly enlarge with every advance in design. On sea the motor-boat was already in superabundant evidence, and the oil-engine had been largely and very usefully applied to propulsion on canals, as

¹ "Gas-Engines for Ship Propulsion." Transactions of the Institution of Naval Architects, vol. xlviii, p. 105.

in Holland. With a completely satisfactory engine it would be adopted in larger ships. But a very large portion of the installations made had been engines only capable of using gasolene or very light oils. These, as the Author stated, could be used only for special vessels. Gasolene was rapidly rising in price, and was often difficult to obtain; but beyond that it was exceedingly dangerous, and many accidents had attended its use. When a much lower grade of oil could be successfully substituted, the use of any highly inflammable oil on board ship was sure to be strongly discouraged. In speaking of heavy oils, a distinction should be drawn between crude oils, from which none of the inflammable ingredients had been extracted, and the residuum. The crude oils were the principal source of the fine mineral oils, from gasolene down. When these were extracted there was left a large proportion of the original oil which was hard to burn and must always remain cheap; indeed, at present it was of little commercial value. Using crude oils in an engine meant diminishing the source, and consequently increasing the cost, of the high-grade oils. Crude oils also were frequently dangerous, as the lighter hydrocarbons easily separated and might readily form an explosive mixture with the air in a closed tank, such as must be used on shipboard. On the other hand, the lower distillates forming the residuum were perfectly safe and could not be burned unless in contact with incandescent surfaces, or by other special means. An applied match or torch was extinguished. The calorific values per pound of these distillates were, however, within 10 or 12 per cent. of those of the light oils. The Paper especially interested Admiral Melville because, about 14 months ago, his firm, Melville and Macalpine, was asked by the Industrial Development Company of New York to make a series of tests of the Goodspeed engine, which engine was the outcome of many attempts made by them to burn these low-grade oils successfully. He had therefore gone very carefully over nearly all the ground which the Author traversed, and could fully appreciate his clear statement of the problems involved and the difficulties to be overcome. The firm had entered on the tests of the Goodspeed engine with considerable scepticism, knowing generally the experience of many former inventors. Their expectation that they could produce carbonization had, however, not been verified. They had tried six different cheap oils, of which the two worst were the Standard Oil Company's 26 gravity (Baumé scale), till recently known as "Refuse Oil," and Texas oil of 18½ gravity, which was the residuum remaining after the gasolene and other light oils had been distilled off. Contrary to

Rear-Admiral
Melville.

Rear-Admiral
Melville.

expectations, the engine dealt with these oils in a thoroughly satisfactory manner. The Goodspeed engine had a two-stroke cycle, with a special form of carburettor in which the fresh air, after compression to the initial pressure, was introduced behind the oil. The fresh air and atomized oil, intimately mixed, both travelled over an incandescent surface, at once inflamed, and burned without depositing carbon, beyond a little loose lamp-black, never more than a few grains in weight, which was always found lying on the top of the piston. This was the result even when the engine was run with a deficiency of air, as, through wear from previous experiments and faulty design, it had done in the tests. The engine as made had numerous defects of design, all of which could be readily corrected in a new design, but the essential part—the oil-burning—was entirely satisfactory. The engine tested had two compression-cylinders, making the compression in two stages. In all four-cycle engines the fresh air drawn in during each cycle must be determined by the volume of the power-cylinder, but with a separate compressor or compressors this limitation was quite unnecessary. It had, however, been followed in the engine submitted to them. As the Author clearly pointed out, it would be most advantageous to diminish the air at low powers in proportion to the oil or gas used, thus avoiding the impoverishment of the mixture. This, he showed, was especially important in marine applications, where the power, and consequently the fuel per revolution, fell so rapidly as the revolutions were reduced; and it greatly extended the range of speed and power at which the engine could run—a range absolutely essential in ships at sea. In their proposals for a new design, having marine applications very prominently in view, they embodied an air-compressor which was to be single-stage up to at least 150 lbs. per square inch. For higher pressures or in large installations, it would probably be better to have a multiple-stage compressor. The air-supply was arranged to regulate itself automatically to that required. This could be effected in many ways, of which, however, one seemed to them to be the best; but as this portion of the design had not yet been protected, it would be improper to discuss it. The building of the first engine from this design was already well advanced, and the engine would probably be placed on the market shortly. The indicator-card was that of the steam-engine, and consequently the valve- and reversing-gear should closely resemble the best steam-engine practice. He wished to endorse with emphasis the Author's statement of the advantage in the two-cycle over the four-cycle

engine, in permitting the substitution of eccentrics and slide-valves for toothed gears, countershafts, cams, and trip-valves. He had taken the liberty of specifying these a little more fully than had been done by the Author, who evidently had this whole change clearly in his mind. Being marine engineers primarily, Messrs. Melville and Macalpine had set down these conditions as necessary to a proper design; in fact, they gave the simplest as well as the best design, and one which would be reliable in its action. In such an engine, since the air-valve was open all the time the oil was being injected by the pump, there was no explosion and no possible large rise of pressure through a miss-fire. In all their tests they had never experienced a miss-fire, but should this occur from any cause, the gases would simply flow back to the air-receiver and no sensible rise of pressure would result; hence, no extra strength and weight had to be added for such a contingency. The calorific value of the oil was sufficient to enable a large excess of air to be used—as, indeed, was done in the Diesel engine—and still keep the temperature of the carburettor sufficiently high. They believed 100 per cent. excess would be allowable, thus greatly increasing efficiency and promoting rapid and complete combustion by the presence of an abundant atmosphere of oxygen, at high pressure, surrounding each particle of oil. At lower powers it would be necessary to adjust the mechanism automatically to give less excess of air, for the carburettor-temperature should be constant, and the radiation per pound of oil burned would be increased. As the air entered behind the oil, and in excess, the small amount of burnt gases left in the clearance when the exhaust ended and the compression began, was driven before the fresh charge and did no harm. He believed the mixture of burnt and unburnt gases in some designs of carburettors was a fruitful source of carbonization. In larger installations, on land or sea, their proposal was to adopt the separate air-compressor, and here again he noted with pleasure that they were at one with the Author. In electric-light stations, or where a number of engines worked simultaneously, it would be simpler, more economical, and more convenient, to have one air-compressor for four or five engines, and one spare air-compressor for the station. The advantage of this separation on shipboard, in increased variation of power and uniformity of turning-moment, was fully and clearly pointed out by the Author. At very low powers, running practically with air alone, the carburettor could be kept incandescent by the means used for heating it initially, and thus the engine was kept in readiness for immediate return

Rear-Admiral
Melville.

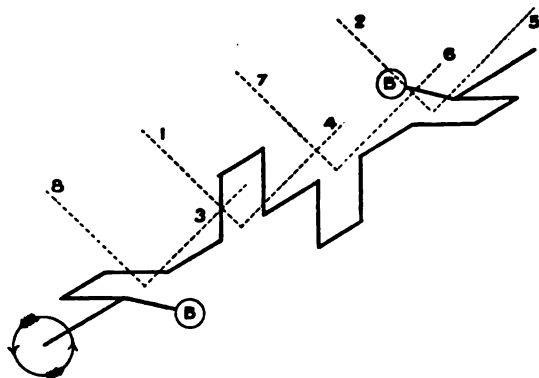
Rear-Admiral
Melville.

to full power. He could see no reason why, with a separate air-compressor having an adjustment for smaller delivery per stroke and reduced pressure, it should not be perfectly simple to work the main engine at anything from full power to less than one-sixteenth of full power. As with atomized oil and a strongly injected current of air gravity was an almost negligible factor, he did not see why such an engine could not be made vertical as well as horizontal. If so, each cylinder could also be made double-acting, as the carburettor could then be laid in any position. There would then be reproduced, very closely, the marine, vertical, double-acting steam-engine. The great saving of weight over a four-cycle single-acting engine with occasional very excessive pressure through a miss-fire, would be still further enhanced by the double-acting cylinder, with only this addition, that the pistons and piston-rods would have to be water-cooled, as was done in many existing gas-engines.

Mr. Sharp. Mr. ARCHIBALD SHARP observed that the difficulty of designing a reversing-gear for a gas-engine had been exaggerated: but a gas-engine reversing-gear could be made a much simpler piece of mechanism than that of a slide-valve steam-engine. An obvious design was to drive the valve cam-shaft by an ordinary differential-gear mechanism, as found on every motor-car. If one of the two equal bevel-wheels of the differential was driven at the same speed as the crank-shaft and the other held stationary, the middle portion carrying the small pinions would be driven at half the speed of the crank-shaft, and might be used to drive the cam-shaft. In order to reverse, the stationary bevel-wheel had to be turned through half a revolution, which operation could be performed at any instant without shock to any part of the mechanism. If this was done while the engine was running ahead at full speed, the exhaust-valve was operated when the piston was at the beginning of its stroke, and remained open till the end of the stroke: the piston thus sucked in a charge of exhaust gas. The second stroke was compression of this gas. If the inlet-valves were mechanically operated, and the inlet cam-shaft was still in the ahead position, the inlet-valve opened at the end of the second stroke, releasing the charge of compressed exhaust gas. During the third stroke, the inlet-valve remained open, gas was again sucked into the cylinder; during the fourth stroke it was compressed, and discharged at the opening of the exhaust-valve at the end of the stroke. Thus by suitably arranging the reversing-mechanism two retarding strokes per cycle might be had in each cylinder, so that the engine should be very quickly brought to rest, previous to starting again in the reverse direction. The two-cylinder-to-each-crank

engine, which had been largely used for light marine motors, seemed Mr. Sharp. to have merits which should render it a desirable type for the largest powers. If the cylinders were at 90° , the primary inertia force for each crank and pair of connecting-rods could be completely balanced by a counterbalance mass on the shaft. The secondary inertia force was in a direction at right angles to the axial plane bisecting the angle between the cylinders, that was, in a marine engine it was parallel to the engine-room floor. Compared with a four-crank vertical gas-engine, the balance of the two-cylinder one-crank engine was much superior. The impulses took place at intervals 3, 5, 3, 5. If four elements were combined, as in the eight-cylinder four-crank engine, the impulses took place at equal intervals. Such engines had usually been made with their

Fig. 17.



four cranks lying in one plane, the counterbalance masses being omitted, like the crank-shaft of the usual four-cylinder motor-car engine. In this case, however, the secondary inertia forces for each of the cranks were all in the same phase, and the resultant was by no means inconsiderable, being $4\sqrt{2} r/l$ times that of the primary inertia force due to one piston and connecting-rod. A better arrangement, by which the resultant secondary inertia force was reduced to zero, was with the four cranks at right angles, as shown diagrammatically in Fig. 17. The ignition in the various cylinders taking place in the sequence indicated by the figures, the impulses were still at equal intervals. The four sets of counterbalance masses (or an equivalent system indicated by BB) must be supplied in this case. The largest unbalanced inertia force was of the fourth

Mr. Sharp. order, being $\sqrt{2} r^3/l^3$ times that of the primary inertia force due to one cylinder. (If $l = 4r$, $\sqrt{2} r^3/l^3 = 0.022$, if $l = 5r$, $\sqrt{2} r^3/l^3 = 0.011$.) The transverse couples due to angular swing of the connecting-rods were perfectly balanced. Smooth running of an engine depending on uniformity of torque, and on perfection of balance of the moving masses, the eight-cylinder four-crank engine should give more satisfactory results than one with vertical cylinders.

29 January, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President,
in the Chair.

The discussion on Mr. J. T. Milton's Paper "Internal-Combustion Engines for Marine Purposes" occupied the evening.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 3671.*)

“The Design of Wayside Stations for Single Lines
of Railway.”

By FREDERICK GEORGE ROYAL-DAWSON, M. Inst. C.E.

IN the early days of railway-construction in India the location and design of station-yards were based more or less on English ideas, which were themselves then in a comparatively undeveloped state. As traffic increased, the stations were extended from time to time in a haphazard manner in the attempt to keep pace with the growth of traffic. But this process could not go on indefinitely, and when the point was reached at which a yard could no longer be adapted to the increased traffic, it had to be entirely remodelled at considerable expense, with complete dislocation of traffic for the time being.

In many engine-changing stations, where the engine-shed had originally been built too close to the main platform, thus preventing the proper expansion of the yard, the press of traffic has at length compelled the removal of the entire locomotive-yard to a more remote site. In other stations, again, where insufficient space had originally been left between the goods-shed and the main line, expansions of the goods-yard have had in consequence to be made on the opposite side of the main line, till the constant shunting of all goods-trains across the main line, which this arrangement necessitated, has become such an intolerable nuisance that an entire remodelling has been inevitable. Such remodellings are going on at the present time in all parts of India, and absorb funds which might otherwise have been available for other purposes. The growth of local traffic, however, is not the only factor which has necessitated the remodelling of station-yards. Another factor which has reacted on the design of many minor wayside stations is the modern demand for through trains at high speeds. This demand on the part of the public has synchronized with a growing recognition, on the part of railway-managers, of the economic importance of getting the maximum use out of their rolling stock. The public and the managers are thus agreed as to the desirability of a certain per-

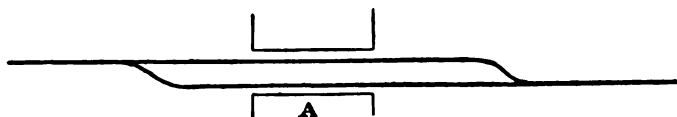
centage of fast trains and the expeditious transportation of goods; and as safety is of the first importance under these new conditions, the principles of safe working have become a special science, the main fruits of which have been (i) interlocking and (ii) automatic block-working. These two mechanical factors of safe working are being introduced gradually throughout the principal lines of India; and although their use is not compulsory, their omission entails the imposition, in the one case, of speed-limits over facing-points, and in the other case, of irksome rules in connection with "line clear" messages. Another factor which threatened to influence the design of station-yards a few years ago was the effect of quick-acting brakes on trains entering turnouts. It was considered that with the use of such brakes there was a tendency to enter turnouts at dangerously high speeds, and that the use of split turnouts, by easing the curvature, would mitigate the evil. But other considerations, to which reference will be made later, prevailed, so that the split turnout has never found favour, except perhaps on a few unimportant lines where fast non-stopping trains are not scheduled.

Types of Stations.—Omitting large termini and junction-stations, which obviously require special treatment, different localities present such a variety of traffic-conditions that wayside station-yards must necessarily be of many different types. Thus, comparing a busy double-line suburban railway, on which the stations are not more than about a mile apart, with a busy double-line section of a trunk-line up-country, having stations, say, 6 or 7 miles apart, it will be seen that, whereas a wayside station on the former consists of little more than an up line and a down line, each with its own substantial platform, and perhaps a trailing cross-over road, the trunk-line station requires in addition an up and a down lie-by siding, and a more or less developed goods-yard on one side, to which access is obtained trailing from both the near and the off track, involving in the latter case a diamond-crossing over the near line. Again, in single-line working the traffic-conditions may be such that (a) all trains stop as a matter of course at every station, as in small branch-lines, or (b) there is a large percentage of fast trains which do not stop at every station, as on important trunk-lines having a fluctuating local traffic. In the former case there may or may not be an up and a down platform, and the station may be approached either by means of a split turnout or otherwise. The number of signals may also be reduced to a minimum, and interlocking is not necessary. But in case (b) the station must be designed primarily for the safety of fast through trains, and secondarily for the development of local traffic; and as this class of station plays the most important rôle in the

transportation problem throughout India, the question of a suitable design has been the subject of much discussion from time to time, and is even now far from being settled. In this Paper, therefore, the Author proposes to confine himself to a consideration of this problem alone, and will begin by reviewing some of the discussions on the subject which have taken place in India during the last few years, and the conclusions arrived at.

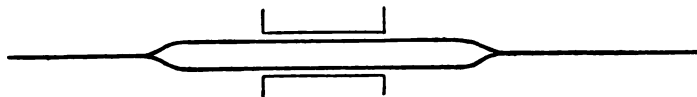
Double-line principle applied to single-line stations.—In 1895, Mr. W. H. Cole, M. Inst. C.E., then Deputy Manager of the Eastern Bengal State Railway, having been on special duty in England for

Fig. 1.



the purpose of studying the question, embodied his conclusions in a Note¹ on the design of yards for single lines in India. Briefly, the type which he advocated was that shown in *Fig. 1*, which involves an up and a down line, with corresponding platforms, trains from both sides entering the facing-points on the straight and running through the trailing-points on the turnout. This design was circulated, with others by Mr. J. R. Bell, M. Inst. C.E., then Consulting Engineer for State Railways, in 1896, amongst various railway officers, for the purpose of obtaining their opinions.² On the assumption that the up and down line principle was desirable,

Fig. 2.



the relative merits of this type as compared with the symmetrical or split-turnout type (*Fig. 2*) were discussed. The general verdict was that for ordinary trains there was little to choose between the two types, except that the symmetrical type tended to minimize the length of the station. But for fast through trains it was held that the split turnout was a source of danger, and that the Cole type was preferable in that respect. Thus the split turnout became eliminated

¹ Technical Papers of the Indian Public Works Department, No. 54, p. 15.

² *Ibid.*, No. 161, p. 6.

for the time being from the discussion, as unsuitable for lines having fast through traffic. It was revived by Mr. F. J. E. Spring,¹ C.I.E., M. Inst. C.E., when Officiating Director of Railway Construction, in 1902, on the ground that with the introduction of quick-acting brakes, trains were liable to enter ordinary turnouts at excessive speeds, the effects of which would be mitigated by the use of split turnouts having easier curves. But in the discussion which followed, the verdict of 1896 was confirmed, inasmuch as the split turnout, although favourable to stopping-trains, was a source of danger to fast through trains; for, however easy the curve might be, the real point of danger was at the switch, when that was set to divert a fast train from the straight. The danger, it was pointed out, lay in the tendency of the leading outer wheel of an express engine to mount the switch, especially if the wheel-flange were somewhat worn; and as the safety of fast through trains was of paramount importance, it was held to be essential that at stations subject to fast through traffic the facing points at least must be on the straight.

It still remained to be considered whether the Cole type (*Fig. 1*) satisfied all requirements, or whether any other type would be preferable. This raised the preliminary inquiry as to whether it was necessary or desirable to preserve the double-line principle. No very clear reason could be given for compelling all trains, whether fast or slow, to take the left-hand road in entering a station beyond the vague plea that it was "English practice." It was thought to simplify matters for the driver, to diminish the risk of collision, and to simplify the signalling, as a train could be admitted by a one-armed home-signal at the facing-points, interlocked so as to be capable of being lowered only when the points were set for the straight. The single-line principle, however, by which all lines would be equally available for up and down traffic, presented no difficulties; for two-armed routing-signals at the points, the higher for the straight and the lower for the turnout, would give the driver all the information he wanted, whilst the List and Morse system of interlocking,¹ as used on the North Western State Railway, illustrated how, at small cost, it could be made impossible for two trains from opposite directions to be admitted simultaneously on to the same line. Thus it was clearly established that the double-line principle was not necessary for safe working. It only remained to be seen whether it was desirable. The system, it was pointed out,

¹ Technical Papers of the Indian Public Works Department, No. 160, p. 4.

² *Ibid.*, No. 63.

necessitated two platforms, so that passengers entering or leaving trains on the opposite side to the station-building would have to cross the line, which they would usually do on the level, even if an overbridge were provided. And even although the platform on the off-side might be merely a surface dressing at rail-level, so that the first cost need not be an obstacle, the difficulty of dealing effectively with an up and a down train at the same time without duplicating the staff was another permanent objection. It might be argued that these drawbacks exist at every station on a double line, but on a double line two platforms are a necessity, whereas on a single line, the necessity for two platforms disappears, and the question is reduced to one of expediency. Regarded in this light it is at once apparent that, (i) with a given staff, trains can be far more economically and effectively dealt with from one platform than from two; and (ii) with a single platform passengers are not exposed to the danger and inconvenience of having to cross the line.

There remains another side of the question to be considered, namely, the facilities for passing trains of different descriptions. The contingency of a slow train being side-tracked for a fast one in one direction, while another train was admitted from the other direction, necessitated the provision of a lie-by siding available for trains from either direction, in addition to the two lines for crossing-purposes. With the double-line principle of working, a lie-by siding would have to take off (preferably in a trailing direction) from each through line; that is, two lie-byes would have to be provided, although not more than one would ever be used at one time. On the other hand, it was seen to be possible, by abandoning the double-line principle of working, and by making either line available for trains in both directions, to do with one lie-by siding only, which would be "trailing" for one direction and "facing" for the other.

Single-line principle.—Thus, the advantages of what may be called the "single-line principle" as opposed to the "double-line principle" in working ordinary wayside stations on a single line were established, and may be summed up as follows: (i) the double-line principle requires two platforms, the single-line principle only one platform; (ii) the double platform involves a larger and more responsible staff than the single platform; (iii) the double platform is more dangerous and more inconvenient to passengers than the single platform, and accidents can be prevented only by the erection of an overbridge and by the provision of extra supervision to enforce its use; the cost of the overbridge and the extra supervision are saved in single-platform working; and (iv) the double-line system involves the construction

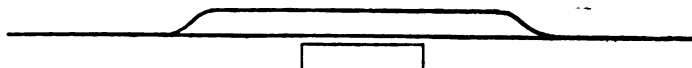
of at least two lie-by sidings, whilst the single line requires only one.

The issue is thus narrowed down to a question of the suitability, or otherwise, of the Cole type (*Fig. 1*) for single-platform working. From this standpoint it is at once evident that trains would be more favoured in one direction than in the other. For, supposing the platform to be placed as shown at A in *Fig. 1*, trains from the right would always have a straight run to the platform, whilst trains from the left would either have to take the first turnout facing, or shoot past on the straight and, after passing the second turnout trailing, shunt back to the platform. The latter procedure would be appropriate enough in the case of crossing trains, but in the majority of cases when the train from the left had a clear platform it would approach by the turnout as a matter of course. The defects of the design, however, are most apparent when a slow passenger-train from the left and a non-stopping express from the right are approaching the station at the same time. The station-master is confronted with the following dilemma: (A) if the slow train is admitted directly to the platform-line, the fast train would have to be put on to the other line by a facing turnout; (B) if, on the other hand, the slow train is put on to the off-line, there would be difficulty in preventing passengers from attempting to cross the intervening track in the face of the fast train. Thus, in the handling of the two trains two alternatives are open, both of which are dangerous. But the danger arises from different sources in the two cases. In case (A) the danger lies in the alignment of the off-line, and would disappear if that were made straight, while in case (B) the danger lies, not in the alignment, but solely in the relative position of the two trains, and is inherent in any system which allows a fast train to pass between a halted passenger-train and a platform. These considerations simplify the issues, for case (A) clearly indicates that the run-through line should be straight from end to end, the other line thus becoming a loop, and case (B) equally clearly indicates that the run-through line should not be between the loop and the platform.

Platform-on-straight versus Platform-on-loop.—The principle of the straight run-through, deduced from case (A), has now been generally accepted by railway-authorities, in supersession of the Cole type. But the principle of the platform-on-loop, deduced from case (B), has not by any means found general acceptance. In fact, when in 1896 and again in 1902 the various Indian railway-officers were asked to choose between the two types shown in *Figs. 3* and *4*, which may be described as "platform-on-straight" and "platform-on-loop," respectively, and both of which satisfy the condition of a straight

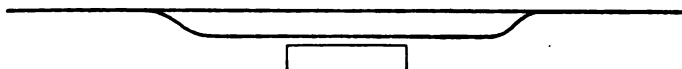
run-through, a surprisingly large number voted in favour of the former, *Fig. 3*. The reason given for this preference was to avoid the lurch at the turnout to which all stopping trains were subject when the platform was placed on the loop as in *Fig. 4*. The danger of allowing a fast train to pass between the platform and a side-tracked passenger-train which the former type involved was lightly considered, and in some cases ignored altogether, by the adherents of this type. It was held that the undoubted comfort of the many should outweigh the problematical danger of the few. On the North Western State Railway, however, where the ratio of non-stopping to

Fig. 3.



stopping trains, including goods-trains, was comparatively large, namely, about 1 to 7, the verdict was strongly in favour of the platform on the loop, *Fig. 4*. It would thus appear that there were objections to both types, and that the factor which determined the choice for any particular railway was the ratio of fast to slow trains on that railway. This would imply that, as fast traffic increased, the stations of a given railway should be changed from the first to the second type, and vice versa when the fast traffic decreased, a manifestly absurd proposition. Moreover, there is a general tendency on most railways to increase the number of fast trains. It therefore becomes necessary to weigh the objections of each type *seriatim*.

Fig. 4.



Taking first the platform-on-straight type, the reality of the danger of allowing a fast train to dash between a halted passenger-train and the platform has been proved over and over again. As an argument it might not carry much weight in a civilized country such as England, where passengers and employees are well able to look after themselves. But in India, no amount of supervision is sufficient to keep foolish and careless passengers and employees from attempting to cross the intervening track in the face of an approaching express. Time, also, is lost in side-tracking a stopping train to allow a through train to cross, and if time is limited the probability is that the stopping train will be allowed to remain at the platform

while the fast train is diverted over the loop—a dangerous alternative. Moreover, the long stoppage of a train on a siding facilitates evasion of the ticket-collector, a drawback which, although not serious, must be considered as inherent in the type. There are thus three permanent objections to this type, while the sole feature in its favour is the straight run for all but crossing trains.

Considering next the platform-on-loop type, the sole objection to it is the lurch to which stopping trains are subjected on taking the turnout. This lurch, it is contended, is a three-fold evil. It is dangerous when turnouts are taken at excessive speeds, as often occurs when quick-acting brakes are used; it is always unpleasant; and it increases the wear and tear of the permanent way as well as of the rolling stock. The risk of taking turnouts at excessive speeds is, however, a relative rather than a positive danger. As interlocking prevents the risk of splitting the points, the danger is confined to two sources, namely, the risk of the outer leading wheel of the engine mounting the switch, when the flange is unduly worn, and the overturning tendency due to the necessarily limited superelevation. In either case the risk depends on controllable factors, namely, the condition of the tires, the speed of the train, and the curvature, etc., of the turnout. A practical limit to the speed is derived from the fact that the driver has to bring his train to a standstill at the platform. This in itself is a safeguard, whatever arbitrary restrictions of speed over turnouts may be imposed, for experience shows that however prone a driver may be to ignore speed-restrictions, stopping trains do not in practice enter turnouts at a greater speed than about 30 miles per hour. Accepting this limit, there would be no excuse for an engine mounting the switch if the wheel-flanges and the points were kept in reasonably good order, as they should be; in fact, even with flanges worn to a sharp edge, mounting is extremely unlikely to take place in ordinary practice. With regard to the danger of overturning, or of broken springs, it ought not to be impossible to design a turnout capable of taking a train with safety at 30 miles per hour. On the Indian standard gauge (5 feet 6 inches), with tracks 15 feet apart, centre to centre, curves of about 1,600 feet radius, with crossings 1 in 12 and switches 15 feet in length, are frequently traversed by trains at 30 miles per hour (against rules, it is true) with impunity. If this is held to be dangerous the remedy would appear to lie in easier curves and longer switches, rather than in speed-restrictions, for as long as the latter are imposed, much of the advantage of quick-acting brakes is lost, and train-movements are unnecessarily hampered. But the Author is inclined to believe that the standard 1 in 12 turnouts, if

scientifically laid out and fitted with 18-foot or 21-foot switches, and properly maintained, could be made available for much faster traffic than is at present allowed. In this connection the question of whether a certain amount of superelevation could be given at the points without detriment to the running-qualities of the straight road is worthy of investigation. But these are technical details which need not be discussed here. They are alluded to merely for the purpose of indicating the possibility of improving the design of turnouts, so as to take trains comfortably at 30 miles per hour, without materially increasing the length of a station-yard. The foregoing remedies would also have the effect of mitigating, to a large extent, the discomfort of the lurch. The increased wear and tear of rolling stock and permanent way on the turnout is confined in the present case to the extra amount caused by fast trains; but as the majority of the trains using the turnout would not be fast trains, the objection under this head is hardly worth considering.

A simpler remedy than any of the foregoing for the evils of the platform-on-loop type is suggested by certain existing practices. The first practice to which reference will be made is that on certain railways, when two passenger-trains cross at a wayside station, the first train draws up at the platform as a matter of course (whether the platform is on the loop or on the straight), and the second train draws up on the second line, clear of the rear of the first train where it is at once dealt with. The second train thus does not get the benefit of the platform at all, but, as far as the Author has observed, no inconvenience is caused thereby, either to the passengers or to the staff, provided the space between the rails is levelled up and dressed with fine metal, and provided the platform is not inconveniently high. Where, as at many wayside stations, the platforms are of the "flush" or rail-level type, the second train suffers practically no disadvantages whatever over the first. Moreover there is no danger in crossing the track in this case, because the crossing is done in rear of a train that has just arrived, so that no one can get run over unless the first train is backed. Even in the latter contingency the danger is very remote, for at worst the backing could only be due to shunting movements in front, the effects of which would not reach the rear of the train without timely and audible warning. The second practice to which it is desired to draw attention is the use of "flush" or rail-level platforms at many wayside stations. To the average third-class passenger of India a high-level platform is an unnecessary luxury. The carriage foot-boards afford all the facilities necessary for egress

and ingress; in fact, on occasions when goods-wagons have to be employed for the conveyance of passengers (as frequently occurs when there is a shortage of carriage-stock), it is found that passengers, whether male or female, have no difficulty in getting into them from any platform-level. The Author does not defend the practice of using goods-wagons for passenger-traffic, but the fact is cited in support of the contention that, with proper coaching-stock, raised platforms are not indispensable for wayside passenger-traffic, either on the 5-foot 6-inch or the metre gauge. This point being established, and considering that trains are occasionally dealt with on the second line without inconvenience, the Author ventures to suggest that if flush platforms were generally adopted at wayside stations, and extended up to the second track (as they might easily be) there would be no need to bring stopping trains on to the loop at all, except for crossing-purposes. If this principle were accepted, the main objection to the platform-on-loop type of station would disappear altogether, as the loop would then be used only on special occasions, *e.g.*, by the first of two passenger-trains which have to cross, or by a passenger-train crossing a goods-train. It would then only be necessary for the station-staff to see that passengers waiting for a train did not spread themselves beyond the limits of what may be called the permanent or "waiting" platform, which might be slightly raised or otherwise demarcated to emphasize its functions. In short, if the three objections to the platform-on-straight type be set against the three objections to the platform-on-loop type, it is found that the former outweigh the latter at every point, for the former contain unpreventable elements of danger, whereas in the latter the danger element is reducible to one of discomfort only, and this can be mitigated or eliminated entirely by the method just suggested.

Position of Platform in Relation to Traffic.—Assuming that the platform-on-loop type is adopted, the next question is whether it matters from which side of the main line the platform takes off. This question has also been ventilated, and the general consensus of opinion is thus summed up by Mr. C. W. Hodson,¹ C.S.I., M. Inst. C.E. :—

(i) Fast or heavy traffic calls for continuous brakes, and the adoption of continuous brakes with fast traffic necessitates interlocked routing-signals, which render it unimportant which side of the main line the turnout takes off.

(ii) Consequently there is no need to put either the loops or the

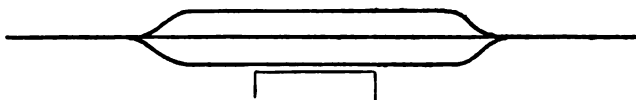
¹ Technical Papers of the Indian Public Works Department, No. 160.

platform uniformly on any particular side of the line, but in the absence of any special reasons to the contrary the loop may preferably be put on the side on which the line will eventually be doubled.

As regards the latter portion of the second paragraph, the Author has seen the principle of uniformity carried to extremes. One side of the line is selected for future doubling (a contingency usually more or less remote), and all platform-loops are placed on that side whether it suits the local traffic or not, with the result that in many cases a fairly important town, which has been keenly interested in the construction of the line, finds itself finally on the wrong side of its station, to which access can be gained only by means of a remote level crossing at the extreme end of the yard. In the opinion of the Author, the more elastic principle of locating a platform on whichever side is more convenient to local traffic is preferable, in that it tends to foster better relations with the public, and simplifies the work of the traffic-department, while it need not prejudice the question of future doubling; for supposing a loop to occur on the opposite side of the line to that selected for doubling, matters could easily be put right, when the need for doubling arose, by a local re-alignment involving a lateral deviation of 15 feet one way or the other from the original main line. In the absence of any special reason to the contrary, it would of course be proper, as pointed out by Mr. Hodson, to put the loop on the doubling side. This would occur, for instance, when a crossing-station serves half-a-dozen unimportant villages equally on both sides of the line.

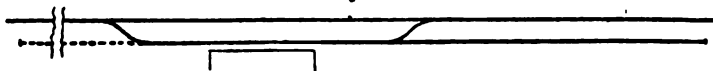
Lie-byes.—The location of a lie-bye, to meet the contingency of a slow train being side-tracked for a fast one in one direction, while another train is being admitted from the opposite direction will next be considered. From a traffic point of view the simplest device would be a second loop on the off-side of the main line, as shown in *Fig. 5*; but the paramount importance of safeguarding fast trains necessitates the use of some form of interlocking, so as to secure the isolation of the run-through line. Traffic conveniences must therefore be governed by the price which the Administration is prepared to pay for their safety. Regarded in this light, it is evident that the fewer facing-points there are on the main line, the cheaper the interlocking will be, and consequently the simpler the working, whatever system may be adopted. In fact, it may be taken as a general rule that it does not pay to have more than one set of interlocked facing-points each way in an ordinary wayside station. This being the case, the type illustrated in *Fig. 5*, which has two sets each way, must be rejected as too expensive, although undoubtedly convenient, and it

is therefore necessary to take the lie-bye off the platform-loop. But as the platform prevents the lie-bye from taking the form of a second loop, the form eventually adopted is necessarily that of a long dead siding, as shown in *Fig. 6*. This is the type now generally adopted on State Railways, and is the cheapest form from the point of view of first cost. The shunting of a train into the lie-bye and its subsequent extrication are tedious and troublesome operations, and in some cases a certain amount of manœuvring is required, as for instance when a stopping passenger-train from the left and a slow goods-train from the right arrive in succession, and the latter

Fig. 5.

has then to be side-tracked for a fast through train from the right; in fact, in this case, if pressed for time, the goods-train could not be got into the lie-bye without great delay, and the probability is that, in order to save time, the passenger-train would have to go there while the goods-train occupied the loop. Such cases, however, are usually rare, and the temporary inconvenience involved has hitherto been accepted as inevitable. The inconvenience would still exist even if the lie-bye were placed in the alternative position shown by the dotted line in *Fig. 6*, or in both positions. On this point the Author will have something more to say later on.

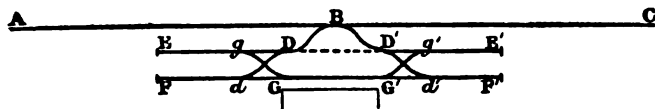
Goods-Yards.—On the question of the development of a local goods-

Fig. 6.

traffic various opinions have been held, some officers being in favour of having the goods-shed opposite the passenger-platform, so as to be under the eye of the station-master, rather than on the same side, where it would necessarily be some distance off, imposing on the station-master a certain amount of trouble and loss of time in walking backwards and forwards, with the alternative of neglecting either the goods-work or the station-work. On most wayside stations of this class the superior staff consists only of a station-master and his assistant, who work by reliefs, only one being on duty at a time; and the man on duty has to combine the duties of train-signaller and goods-clerk. Two or three menials complete the establishment.

There is thus no doubt that a goods-shed opposite the station-building would be more convenient from the station-master's point of view. This arrangement, however, means a reversion to the type shown in *Fig. 5*, which has been shown to be too expensive by reason of the extra interlocking involved. Moreover, from the point of view of the public, if the passenger-platform is on the natural passenger-traffic side of the line, as it ought to be, the natural goods-traffic will almost invariably be on the same side. Therefore, the type shown in *Fig. 5* would be not only too expensive, but unsuitable to the public. Hence the predilections of the station-master have to give way to the combined exigencies of economical working and public convenience; and if it is found in a rush of traffic that one man cannot efficiently attend to both the station and the goods-work, the proper remedy would be to engage an extra man temporarily. Thus at every turn the design of a station-yard of this class involves a choice of evils; and having arrived at the conclusion that the goods-yard must usually be on the same side as the passenger-platform, the next step is to consider how it should be laid out. In many cases the steps taken for creating

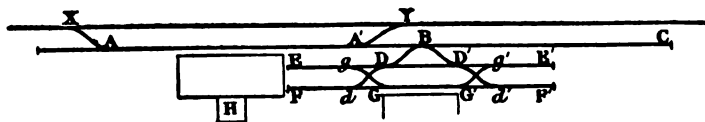
Fig. 7.



a goods-traffic are tentative in the first instance, and very often an extensive traffic is developed from very small beginnings. It is therefore very desirable that the first sidings laid down, however modest, should form part of the future design of a fully developed yard. The goods-shed has to deal with both outward and inward traffic; therefore the sidings should be so arranged that a goods-train from either direction can readily detach and pick up wagons, whether loaded or empty, from suitable sidings in the neighbourhood of the goods-shed. Let B (*Fig. 7*) be a point on the train-siding A B C opposite the goods-shed G G'. An engine arriving from A with wagons to be detached would draw up in B C, clear of B, then shunt back over a cross-over B D, giving direct access to two sidings D E, DdF, one of which would be kept clear to receive the "inward" wagons, whilst the other would contain the "outward" wagons, previously assembled in readiness to be attached. Thus, with a minimum of shunting and in the shortest possible time, the engine would have detached its inward and attached its outward load, and returned to B C ready to rejoin its train in A B, and thence proceed on its journey. Similarly, a train arriving from the direction of C

would require a corresponding cross-over B D' and sidings D' E', and D'dF'. It only remains to provide access from both sets of sidings to the goods-shed. This can be done most compactly by providing a platform-line d G G'd and inserting scissors cross-overs Dd, Gg, D'd, and G'g'. The movements of individual wagons between the platform and the various sidings would of course be effected by hand shunting. On the North Western State Railway, where this type of goods-yard is in vogue, the sidings are long enough to hold, say, fifteen wagons each, and the platform-line a similar number. If further platform-accommodation is required, one of the scissors cross-overs is simply moved further out, say to double the distance, and the platform-line is extended to hold thirty wagons. Ordinarily, not more than fifteen wagons are ever likely to be received or despatched in one direction at a time, so that dead sidings long enough to hold fifteen wagons each are found to suffice, but a platform of double that capacity may be necessary in case of up and down traffic being equal in bulk at any time, as sometimes happens. Further accommodation may be given by joining up D D', as shown by the dotted line. For stations in embryo the portions F G and F' G' and the cross-overs Dd and

Fig. 8.

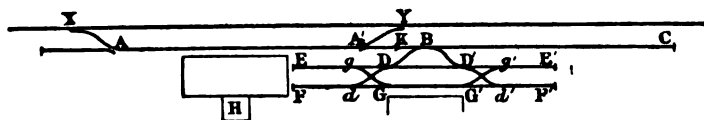


D'd' are omitted. In the earliest stages, when the traffic prospects do not amount to more than one or two wagons a day in either direction, no platform is provided, and the "yard" consists of a single cross-over B D or B D', leading from the train-line to a short siding E E' on which all traffic is dealt with. If a shed is required, it is made portable, so as not to prejudice future extensions.

Accepting Fig. 7 as the normal type of goods-yard, based on common-sense principles, the next step is to fit it into the station-plan, Fig. 6. It has already been shown that it must be on the platform side. The first device that suggests itself is to merge the approach-siding A B C of Fig. 7 into the lie-bye in Fig. 6. This is, in fact, what is usually done, the only objection to it being that, in a certain contingency, already alluded to, a goods-train on arrival might find the lie-bye occupied by a passenger-train, the main line being cleared for an expected through train. If such a contingency is likely to be of frequent occurrence, a second lie-bye can easily be put in as shown by the dotted line in Fig. 6, and one of these lie-byes,

say the right-hand one, reserved as the base of the goods-yard. Usually the second lie-by is not necessary, a short dead siding being sufficient there as a trap. The yard will then finally take the form shown in *Fig. 8*. The minimum distance between the station-platform and the near end of the goods-platform is fixed by the length of the sidings D E and G F, which must be at least equal to the length of fifteen wagons plus the length of the scissors cross-over. The station-platform being 600 feet in length, the distance from the station-building H to the nearest point of the goods-platform G, amounts to about 850 feet, on the standard gauge. Hence if the goods-platform is 720 feet in length (sufficient for thirty wagons) the station-master's average walk from the station-building to the centre of the goods-platform is 1,210 feet, or say 400 yards, which in the hot weather might be traversed in 5 minutes.

Interlocking.—The means by which such a yard can be interlocked have still to be considered. On the North Western State Railway, where the List and Morse key-locking system¹ is in use, the goods-yard is trapped at K, between A' and B (*Fig. 9*) and the points A and A' are kept normally locked off the loop, and cannot be unlocked

Fig. 9.

and set for their respective dead sidings when a loop-signal is lowered at the facing-points X or Y of the main line. The result is that no train can be admitted directly into a dead siding from the main line. It has to be brought first on to the loop, where it then has to wait till the desired road is made. This is done in the following manner. The points A' and the trap K are set and locked normally as shown in *Fig. 9*, by means of a Hepper double-key lock at K and a single-key lock at A'. To set the points for the siding, a key, called the "station-key," is obtained from the station-master, the issue of which locks the loop-keys, thus preventing loop-signals from being lowered while the "station-key" is in use. This station-key is taken to the double lock at the trap K and inserted in its proper hole and turned. This releases the switch, which must next be reversed and set for the siding. This releases a key, called the

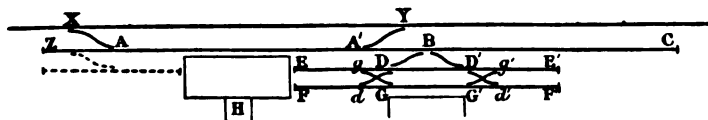
¹ Technical Papers of the Indian Public Works Department, No. 63.

² *Ibid.*, No. 181, Plates xx and xxi.

"points-key," from the other compartment of the double lock. The extraction of the points-key prevents the trap from being again reversed, and so locks up the station-key for the time being. The points-key is then inserted and turned in the lock at A', thus unlocking the points, which can then be reversed and set for the siding. This reversal locks up the points-key, so that when the siding is in use neither the points-key nor the station-key can be extracted and no loop-signal can be lowered. Consequently, if it is desired to admit a running train on the loop, the siding must first be restored to its normal setting and locked off the loop and the station-key returned to the station-master before the key for the loop-signal can be issued. It will be understood from the foregoing that any key locking-system, although securing at small cost the absolute safety of the running lines, entails a certain amount of delay in bringing the siding into use, and again in restoring it to its normal setting. A rodding system would be more expeditious, but the cost would usually be prohibitive for wayside stations. These drawbacks are beginning to be realized more and more every day. The more complete the interlocking, the more paralysing is its effect on ordinary traffic-operations. The safety of through trains is secured at the expense of station-to-station traffic. If the interlocking is only partial, ordinary traffic may be expedited, but the security of through trains is no longer guaranteed. On a certain Indian railway, where platforms are almost invariably on the main line, and a second loop takes off the first, the interlocking is confined to the facing-points on the main line. Sidings are not trapped, and the only protection is that afforded by the use of Scotch blocks which may or may not be left open. This cannot be considered a satisfactory state of affairs, but there are only two fast trains a day each way on this line, and as long as these suffer no mishap there is a tendency to be satisfied with existing arrangements, especially as they facilitate the handling of ordinary traffic.

Suggested Modifications.—Whilst it is illogical to approve of partial interlocking, it must be admitted that excessive interlocking sometimes constitutes a serious inconvenience in a rush of traffic. It raises the question whether, after all, a little elasticity should not be permitted in applying to wayside stations some of the tenets of interlocking, which in their entirety constitute a "counsel of perfection" difficult to attain in practice. For instance, the first golden rule of interlocking is the complete isolation of running-roads, and the second is the trapping of all lines leading from goods-lines and sidings to the running-roads. Both these conditions are fulfilled in the North Western State Railway  wayside

station, the running-roads being the main line and the loop. But the isolation of the loop as well as the main line throws difficulties in the way of handling ordinary traffic. Reference to *Fig. 9* will show that a train on the lie-bye must be completely locked in before another train can be admitted into the loop. The Author contends that as long as the lie-bye is used only by *bona fide* trains, i.e., trains consisting of vehicles coupled to one another and attached to an engine in steam, it is not necessary to lock it off from the loop, as with such trains there would always be a responsible man at the near end. If this point is conceded, it is possible to introduce the simple arrangement shown in *Fig. 10*, where the erstwhile loop becomes a disconnected line, to which access from the main line is gained by cross-overs XA, YA' from the facing-points X and Y. Each cross-over would be rodded and worked by a single lever in the same way as simple facing-points, whatever system of interlocking were used, the only difference being that the moving of a cross-over would involve a slightly greater effort than the moving of a single set of points. The only extra rodding necessary would be that required

Fig. 10.

to connect X with A and Y with A'. The safety of fast through trains is secured as before. It only remains to consider what risks may be incurred by a stopping train entering the loop. The first risk is that the cross-over may be reversed too soon after the train has cleared the facing end, which may be unlocked immediately after its passage, and before it has cleared the trailing end, which it would not be practicable to lock. But no more serious accident than burst trailing points would ensue from that remote contingency; and even if these burst trailing-points were not detected before the next loop-train from the opposite direction entered them facing, the ensuing derailment would not be serious nor likely to foul the main-line. Point-indicators would of course be used. The only other risk is that of runaway wagons fouling the loop. As regards this contingency, there would never be any occasion, nor any inducement (even if there were no orders on the subject) to stable wagons on the lie-bye siding A' B C; and the short dead siding A Z is merely intended as a trap, although possibly a short siding for spare carriages might be connected with it by a cross-

over, as shown by the dotted lines. Hence, if any loose wagons escaped from the goods-yard they could only get on to the lie-by when the cross-overs B D, B D' were set for that line. It would then require a wind blowing in the direction C to A or a falling gradient in that direction to cause these wagons to foul the loop. The gravitation factor of the problem could be met by making the cross-overs B D, B D' fall, say, 1 in 50 towards the goods-shed sidings, putting the latter at a lower level. As a further precaution the lie-by might be given a slight fall from A' to C, but this is not altogether desirable, as trains using it would have difficulty in getting out again. It is better that it should be level. Runaways can then be caused only by a sufficiently strong wind blowing from C to A. Wind in this direction would not affect the wagons on the sidings E and F, but it might start those in the sidings E' and F'. The conditions for a runaway then would be (i) the cross-over D' B must be set for the sidings, (ii) there must be loose wagons in one of the sidings E' and F', (iii) the Scotch blocks must be open, (iv) the wind must be in the direction C to A, and must be sufficiently strong to blow wagons up the 1-in-50 gradient over D' B. Hence if any one of the foregoing factors can be circumvented the problem is solved, and there can be no runaways. To circumvent the first three factors, by interlocking or otherwise, would be costly; but the fourth can be nullified by the simple device of erecting a wind-screen to protect the sidings E' and F', if they are not already sheltered by existing local features.

It will be seen that the station is now so interlocked that the safety of the through line is absolutely, and of the loop practically secured, whilst access to the lie-by and goods-yard can be obtained at all times without the delay entailed under the systems previously described, where the lie-by and goods-yard are normally locked off from the loop as shown in *Fig. 9*. Moreover, it will be seen that as long as the loop is not required for a running train (which would be the normal state of affairs) the lines B A and B C (*Fig. 10*) form perfect isolated shunting-necks for goods-trains in both directions. It is true that when a passenger-train is halted on the main line opposite the platform the portion of neck B A available for shunting purposes would be temporarily curtailed, so as not to screen the passenger-train. But as shunting operations could be suspended at any instant at a sign from the station-master this arrangement would present no traffic difficulties. The great advantage is that there are no interlocked traps or points to prevent the siding from being available for use at any moment, and thus a great saving of time is effected when there is any shunting to be

done. This type (*Fig. 10*) involves a quasi-infringement of the interlocking rules, which prescribe generally for the protection of running-roads without reference to their individual importance. But, as in wayside stations the main line alone is used by fast through traffic, the protection of which is the *raison d'être* for interlocking, whilst the loop is used only by stopping trains, for which the protection afforded by interlocked traps would not ordinarily be considered necessary, it appears to be a reasonable compromise, in this class of station (assuming that the exigencies of shunting preclude the general adoption of the more perfect type, *Fig. 9*), to treat only the main line as a running-road for interlocking purposes.

Dead Sidings versus Loops.—The inherent defect of the dead siding form of lie-bye is the delay involved in backing a train into or out of it. When traffic is heavy, such delays mount up. Even with the simplest system of interlocking, the time spent by a heavy train in entering and emerging from a dead siding is almost equal in many cases to that which it would occupy in running between two neighbouring stations. On account of this defect, although a yard arranged on the plan just described would reduce the delay to a minimum, traffic-officers do not take kindly to the dead siding principle for crossing-purposes, and would welcome any loop-system that combined facility of movement with safe working. Where the platform is on the straight, it is customary for a second loop to take off the first, and although in the absence of efficient trapping this arrangement is not conducive to the safety of fast through trains, it undoubtedly saves time when three trains have to be dealt with. It is worth while considering, therefore, whether a second loop can be provided without sacrificing any of the principles involved in the adoption of the type shown in *Fig. 10*.

Accepting the two hypotheses that a raised platform is not necessary and that tracks may intervene between the "permanent" platform and a stopping passenger-train, it would be easy, by setting back the permanent platform another 15 feet, to introduce a second loop between the first loop and the platform. The straight would still be used, in the ordinary course, for the reception of trains, passengers merely having to cross two intervening tracks instead of one; and for the crossing of two trains the straight and the first loop would be used as before. But when three trains have to be accommodated there is no doubt that the second loop would be used on all occasions in preference to the lie-bye. The latter would thus become a goods-siding only. In the case of side-tracking a goods-train and a passenger-train, the passenger-train would take the platform-line and the goods-train the middle line, as a matter of course, no

matter which train arrived first. The goods-train might even be able to carry on its shunting during the interval. The second loop therefore presents considerable advantages, but it is doubtful whether it could be safely used without complicating the interlocking arrangements. Supposing the interlocking to be initially confined to the facing-points of the main line, combined with the use of coupled cross-overs as described in connection with *Fig. 10*, the insertion of a second loop would involve two sets of facing-points for all trains turned off the main line. If such trains had continuous brakes, it would certainly be necessary to ensure the correct setting of the second facing-points before the loop-signal was lowered. This could only be done by extending the system of interlocking so as to provide for three-armed interlocked signals at the main-line facing-points, the third arm referring to the second loop. The expenditure involved in such extra interlocking would not be justified except perhaps at selected stations of growing importance. But in laying out a new line of railway the future development of wayside stations can never be foreseen with any certainty. It has often happened that a station which has originally been inserted midway between two other stations merely for crossing-purposes, and for no other reason, has subsequently developed a local traffic which has necessitated in the course of a few years its expansion out of all recognition. It is therefore necessary, when first laying out a station, no matter how insignificant its traffic prospects may appear at the time, to allow for future development. The Author therefore ventures to suggest that when the platform-on-loop type of station, as shown in *Fig. 9* or *Fig. 10*, is adopted, the permanent platform should be set sufficiently far back to enable a second loop to be put in at any future time, if found necessary. This involves merely placing the station-building about 15 feet farther back than it would otherwise be in the first instance.

In conclusion the Author desires to acknowledge the assistance afforded him in the preparation of this Paper, not only by personal intercourse with various railway-officers in India, but also by the various publications of the late Technical Section of the Indian Public Works Department, issued under the personal direction of Mr. C. W. Hodson, C.S.I., M. Inst. C.E., late Secretary to the Government of India for Railways.

The Paper is accompanied by ten diagrams, from which the Figures in the text have been prepared.

(Paper No. 3637.)

"Distribution of Stresses in Plate-Girders."

By CYRIL WALTER LLOYD-JONES, Stud. Inst. C.E.

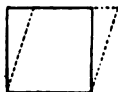
It is customary in designing the riveting of plate-girders to make the strength of the flange-riveting per unit length of flange equal, at any point, to the shearing-force at that point divided by the depth. A deduction may be made from this shearing-force to allow for the bending-moment taken by the web, but this deduction is usually too small to be taken into account.

This method of design, applied to shallow girders of small span, leads to abnormally strong riveting, and is frequently discarded by designers as not applicable to the reaction-ends of girders. Many girders are carrying loads in a satisfactory manner, and showing no signs of weakness in the riveting, although at certain places the riveting, judged by the foregoing method, would appear to be greatly over-strained. At the reaction-ends of girders of short span, the web is frequently sufficiently strong to take the bending-moment for a short distance; consequently it seems quite reasonable to suppose that, where riveting is weak, the stresses due to bending may not follow the ordinary law of distribution over a compound section, but may be higher in the web than in the flange. The following is an attempt to estimate what form such a distribution would take.

Relation between Stress and Strain in a Flange-Web Connection as affecting the Distribution of Stress in a Plate-Girder.—The ordinary method of designing plate-girders is based upon certain assumptions, one of which is, that the intensity of fibre-stress is proportional to the distance of the fibre from the neutral axis. This relation between the fibre-stresses is arrived at by consideration of the fibre-strains, and is applicable when the girder-section is, or behaves in the same manner as, one entire and continuous body. A plate-girder, however, does not consist of one continuous piece of material, but of several pieces joined by means of rivets; consequently the distribution of stress in such a girder may differ from



line" distribution if the properties of the section so composed differ from the properties of a similar continuous section. The proof that the intensity of fibre-stress is proportional to the distance of the fibre from the neutral axis depends on the expressions for tangential and direct stress in terms of the rates of strain at any point of a homogeneous body. These expressions are deduced by assuming that the deformation under shear is of the form shown in *Fig. 1*. If a small portion of the material of a plate-girder be considered, the portion being so situated that it is partly in the flange and partly in the web, it is quite possible that it would not be deformed in this manner under a tangential stress.

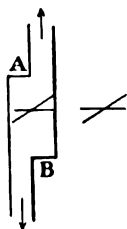
Fig. 1.

If slip occurred in the riveted connection, the deformation would be as shown in *Fig. 2*, and the expressions connecting stress and strain could no longer be applied.

The connection here considered is the riveted flange-web connection. In plate-girders there may be one or more such connections; there is invariably one connection between web and angle-bars, this connection consisting of two shear-surfaces; there may be also a second connection between the angle-bars and a plate, and further connections between one plate and another. All these connections are essentially

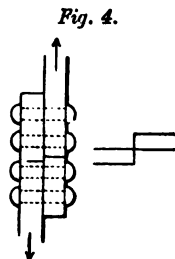
Fig. 2.

the same and may be treated similarly. The girder considered will be supposed to consist of a web of depth h , and flanges, the areas of which are located at the extremities of the web, and therefore at a distance h apart. Each flange-section is supposed to consist of several distinct areas, connected with each other and with the web by rivets in shear. The rivet-area in shear per unit length of flange is denoted by λ and the area in shear is considered as continuously and uniformly distributed along the flange.

Fig. 3.

If a piece of material of the form indicated in *Fig. 3* were stressed so that the section AB was in shear, the strains produced would be such that a line drawn at right-angles to AB would become a straight line inclined to AB, and therefore the work done on the section AB would be zero. In the case of a section made up of rivets, however, the actual behaviour of the joint under stress depends on many conditions, particularly on the properties of the material of which the rivets are made, and on the manner of manufacture of the joint. It is certain that deflection

would take place under the loads to which the joint would be subjected if the distribution were that ordinarily assumed, and this deflection would be of the nature of that indicated in *Fig. 4*; one plate would actually slide on the other. This consideration shows that the flange-web connection, if stressed to the extent indicated by the assumed distribution of stress in a girder, would not behave in the same manner as a continuous section. A certain amount of sliding would occur between the web and the flange, and by such sliding work would be done on the rivets. No corresponding action by which, apparently, work is done on a horizontal section of indefinitely small width takes place in a stressed solid beam.



In a solid beam, considering a section by two parallel and vertical planes at right-angles to the geometrical axis, work is done in the following ways:—

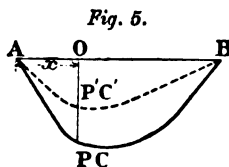
- (a) By a bending-moment acting on the flanges.
- (b) By a bending-moment acting on the web.
- (c) By a shearing-force acting on the web.

In a riveted beam, work is done in the following ways:—

- (a) By a bending-moment acting on the flanges.
- (b) By a bending-moment acting on the web.
- (c) By a shearing-force acting on the web.
- (d) By a shearing-force acting on the rivets, as previously described.

The distribution of stress in a riveted beam, therefore, does not correspond exactly to that in a solid beam of the same section, if the shearing-stress on the rivets is sufficiently great to cause sliding to take place.

Let the curve *ACB* (*Fig. 5*) represent the bending-moment on a riveted girder, and the curve *AC'B* the bending-moment taken by the flanges: then the differences between the ordinates of these two curves will represent the bending-moment taken by the web. In a solid beam, these two curves are very simply related; the ordinate of one bears a constant ratio to the ordinate of the other, the ratio being that of the moment of inertia of the whole section to that of the flange alone.



Taking the case of a riveted beam, let the ordinate of the curve *ACB* at any point be *M*, and let the ordinate of the curve *AC'B* at any point be *m*. *M* is then a function of *x*, depending on the

loading, and m is some unknown function of x . The bending-moment taken by the web is $(M-m)$. In this case the shear on the web at any point is $\frac{dM}{dx}$ and the shear on the rivets is $\frac{dm}{dx}$. The condition determining the value or form of m is obtained by applying the principle of least work. The work done by the four sets of forces above enumerated should be a minimum, and the form which m takes to effect this is its true value. In applying this condition the work done by shear in the web may be neglected, as its value is independent of m and therefore will not affect the value of m to be determined. The work done by the bending-moment in the flange is $\int_{x_1}^{x_2} \frac{m^2}{2EI_f} dx$, and by the bending-moment in the web is $\int_{x_1}^{x_2} \frac{(M-m)^2}{2EI_w} dx$. The work done in the rivet-line depends on $\frac{dm}{dx}$, but the form of the expression for it depends on the relation of stress to strain in the rivets. It will therefore be necessary to study this action before the condition referred to above can be applied.

Form of the Expression for Work done on Rivets in a Flange-Web Connection.—The expression for work done on the riveted flange-web connection of a plate-girder depends on the relation of stress to strain in a riveted joint. Taking the expression for the strain in terms of the average shearing-stress as

$$n = f(s)$$

the value of s , the average shearing-stress, may be substituted.

Thus, if the total shear is $\frac{dm}{dx}$ the shearing-stress per unit area is

$$s = \frac{1}{h\lambda} \cdot \frac{dm}{dx}, \text{ and } n = f\left(\frac{1}{\lambda h} \frac{dm}{dx}\right).$$

Thus the work done is

$$V = \int_{x_1}^{x_2} \frac{1}{2} n \cdot \frac{dm}{dx} \frac{1}{h} dx = \int_{x_1}^{x_2} \left(\frac{dm}{dx}\right) f\left(\frac{1}{\lambda h} \frac{dm}{dx}\right) \cdot \frac{dx}{2h}.$$

To evaluate this expression it is necessary to determine the form of the function $f(s)$. This function, which is the stress-strain curve for a rivet in shear, has been exhaustively investigated experimentally, and results of some of the investigations have been published in the "Proceedings."¹ The general form of the

¹ Minutes of Proceedings Inst. C.E., vol. cxxi, p. 402, and vol. cxxx, p. 332. |

curve appears to be as shown in *Fig. 6*, where AA are points between which no deflection takes place, and the beam would consequently behave as a solid beam. The position of A depends mainly on the workmanship and the quality of the rivets, and undoubtedly in many cases A approaches very nearly to the origin. In this case $f(s)$ would have a simple form, and it will therefore be investigated as an approximate solution of the general problem.

It is conceivable that a joint may be in some cases so loose as to give a stress-strain curve similar to that shown in *Fig. 7*. A rivet which had become loose would undoubtedly give such a curve, the distances OA and OA' being the movement of the riveted members necessary to bring the rivet to a bearing. This may be approximately the case in girders in which the rivets have been allowed to work loose. Probably the stress-strain curve given in *Fig. 6* would be approximately represented by the equation $\sigma = k\epsilon^3$; but this relation leads to results that are difficult to deal with or express in a simple form. In any case the form of the stress-strain curve is probably so variable that nothing is gained by taking other than the simplest approximation to its average form. In the case under investigation the stress-strain curve would be as shown in *Fig. 8*, and the equation for n would therefore be

$$n = f\left(\frac{1}{\lambda h} \frac{dm}{dx}\right) = \frac{k}{\lambda h} \frac{dm}{dx}.$$

Evidently k is a length divided by a stress, so that k may be written $\frac{R}{E}$, where E is Young's modulus and R is some length. An interpretation of R would be, the length of a rod that would give the same deflection as the riveted joint when subjected to a tensional stress equal to the shearing-stress on the rivets. This interpretation of R

Fig. 6.

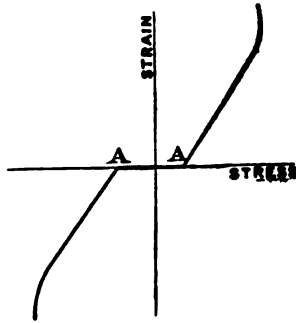
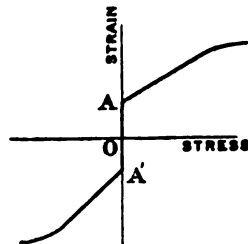
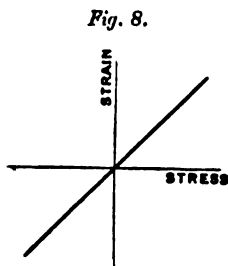


Fig. 7.



is only true, however, when the stress-strain curve of the rivets approximates to that shown in *Fig. 8*. If the riveted joint under consideration contained loose rivets—in which case the stress-strain curve would be of the form shown in *Fig. 7*—the value to be taken for R in order to apply the following results would be very much higher than is compatible with the foregoing interpretation.



The equation for strain may now be written

$$n = \frac{R}{E \lambda h} \frac{dm}{dx},$$

and the equation for work done on the rivets

$$V = \frac{R}{E} \int_{x_1}^{x_2} \left(\frac{dm}{dx} \right)^2 \frac{dx}{2 \lambda h^2} \text{ per row of rivets ;}$$

or, allowing for both top and bottom rows of rivets,

$$V = \frac{R}{E} \int_{x_1}^{x_2} \left(\frac{dm}{dx} \right)^2 \frac{dx}{\lambda h^2} \cdot \cdot \cdot \cdot \cdot \quad (1)$$

The total equation for work done may now be obtained on the assumption of the form of the stress-strain curve given above.

Condition Satisfied by the Distribution of Stresses in a Plate-Girder.—Applying the principle of least work to the distribution of stresses in a plate-girder, it is assumed that the load or reaction is transmitted from the web to the flanges by the agency of the rivets, and that the bending-moment transmitted is determined by this principle—

Let the bending-moment carried by the flanges be m , and the bending-moment carried by the web ($M - m$).

Then the expression for the total work done is

$$V = \int_{x_1}^{x_2} \left\{ \frac{m^2}{2 E I_f} + \frac{(M - m)^2}{2 E I_w} + \frac{R}{E \lambda h^2} \left(\frac{dm}{dx} \right)^2 \right\} dx \quad (2)$$

This expression is the sum of the work done in the flanges, web, and rivets respectively; the work done by shear in the web is neglected for the reason previously given. The expression for work done by shear in the rivets is derived from equation (1).

Solution of the Condition $\int_{x_0}^{x_1} U dx$ a Minimum.—Equation (2) expresses the total work done as a definite integral of m and M in terms of x . M is a known function of x and the value may be substituted for each particular case of loading. The form of the function m is required to be determined, and it is determined so that V shall be a minimum.

Writing only effective terms of V , equation (2) becomes

$$V^1 = \int_{x_0}^{x_1} \left\{ \left(\frac{1}{I_F} + \frac{1}{I_W} \right) m^2 - \frac{2}{I_W} m M + \frac{2 R}{\lambda h^2} \left(\frac{d m}{d x} \right)^2 + \frac{M^2}{I_W} \right\} d x.$$

To make this a minimum¹

$$P = 2 \left(\frac{1}{I_F} + \frac{1}{I_W} \right) m - \frac{2}{I_W} M.$$

$$P_1 = \frac{4 R}{\lambda h^2} \frac{d m}{d x}; \quad \frac{d P_1}{d x} = \frac{4 R}{\lambda h^2} \frac{d^2 m}{d x^2}$$

hence m is the solution of

$$\frac{4 R}{\lambda h^2} \frac{d^2 m}{d x^2} - 2 \left(\frac{1}{I_F} + \frac{1}{I_W} \right) m = - \frac{2}{I_W} M \quad . \quad . \quad . \quad (3)$$

$$a \frac{d^2 m}{d x^2} - b m = -p M \quad . \quad . \quad . \quad (3a)$$

The solution of this equation is

$$m = A \cosh \gamma x + B \sinh \gamma x + Q \quad . \quad . \quad . \quad (4)$$

where
$$\gamma = \sqrt{\frac{b}{a}},$$

and Q is any particular solution of equation (3).

The constants A and B are derived from the condition

$$\left|_{x_0}^{x_1} \frac{d m}{d x} = 0 \quad . \quad . \quad . \quad . \quad (4a)$$

In most cases the function M is algebraical and does not contain any power of x higher than the second; in this case Q is directly obtainable; thus, let

$$M = a + \beta x + \delta x^2$$

substituting
$$m = A + B x + C x^2$$

$$(2 a C - b A) - b B x - b C x^2 = -p a - p \beta x - p \delta x^2;$$

hence
$$Q = \frac{p}{b} \left\{ \frac{2 a}{b} \delta + M \right\} \quad . \quad . \quad . \quad . \quad (4b)$$

Application of the Formulas.—The expression (4) represents the distribution of bending-moment on the portion of the section considered in every form of M that could occur. The variation in the form of the expression (4) for various forms of M is entirely in the

¹ Williamson's "Integral Calculus," chap. xvi.

function Q . This function is in each case obtained from a particular solution of equation (3). A special case occurs when an expression cannot be obtained for M which will apply to the whole length of the beam. This case is of frequent occurrence, as, for example, in the case of several concentrated loads on a beam supported at both ends. In these cases the functions M and F are discontinuous and cannot be expressed by one equation for the whole beam. Considering the case of M being discontinuous, there are several expressions, such as M_1, M_2, M_3 , all of which are applicable between definite limits of x , viz., $x_0 - x_1, x_1 - x_2$. The expression for V then becomes

$$V = \int_{x_0}^{x_1} f(M_1 m_1 \dot{m}_1) dx + \int_{x_1}^{x_2} f(M_2 m_2 \dot{m}_2) dx + \dots$$

As in this case the function (f) is the same for each integral, a series of equations (4) may be written down, one for each segment, the only differences in them being in A, B and Q ; thus,

$$\begin{aligned} m_1 &= A_1 \cosh \gamma x + B_1 \sinh \gamma x + Q_1 \\ m_2 &= A_2 \cosh \gamma x + B_2 \sinh \gamma x + Q_2 \end{aligned}$$

The functions $Q_1, Q_2, \dots$ may be found in each case by actual integration of equation (3) for the particular form of M . Hence, so far as deriving the form of equation (4) is concerned, each of the segments (and therefore each definite integral) may be treated quite separately; the values of the constants $A_1, B_1, A_2, B_2, \dots$ depend on the form of V , and it is necessary to consider how they may be determined. In the case of a continuous form of M , the constants A and B are found from the substitution

$$\left|_{x_0}^{x_1} \frac{d m}{d x} = 0.\right.$$

Proceeding in a similar manner,

$$\left|_{x_0}^{x_1} \frac{d m_1}{d x} + \left|_{x_1}^{x_2} \frac{d m_2}{d x} + \left|_{x_2}^{x_3} \frac{d m_3}{d x} + \dots = 0.\right.$$

Taking each limit separately

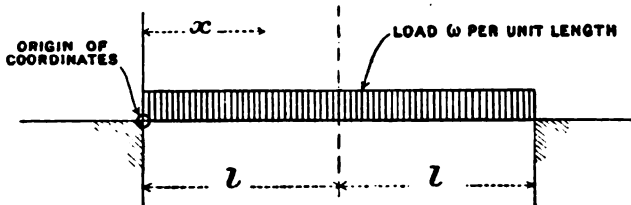
$$\left. \begin{aligned} &\left|_{x_0} \frac{d m_1}{d x} = 0 \right. \\ &\left|_{x_1} \frac{d m_1}{d x} + \left|_{x_1}^{x_2} \frac{d m}{d x} = 0 \right. \\ &\left|_{x_2} \frac{d m_2}{d x} + \left|_{x_2}^{x_3} \frac{d m_3}{d x} = 0 \right. \end{aligned} \right\} \dots \dots \dots (4c)$$

If the number of equations for M be n , there will be n equations for m , and consequently $2n$ arbitrary constants. The number of equations of condition (4c) will be $(n + 1)$, so that $(n - 1)$ additional equations are required to eliminate the constants. The further conditions are derived from considerations of the continuity of the function m . It is evident that the limiting values for adjacent segments must be equal. The following $(n - 1)$ equations are therefore obtained :—

$$\left. \begin{array}{l} \left. \begin{array}{l} x_1 \\ x_2 \\ x_3 \end{array} \right\} \begin{array}{l} m_1 = \\ m_2 = \\ m_3 = \end{array} \right\} \begin{array}{l} x_1 \\ x_2 \\ x_3 \end{array} \left. \begin{array}{l} m_2 \\ m_3 \\ m_4 \end{array} \right\} \dots \dots \dots (4d)$$

Consequently with $(n + 1)$ equations from (4c) and $(n - 1)$ equations from (4d) there are $2n$ equations in all, which suffice to eliminate $2n$ constants from n equations (4). The solution of these equations in certain special cases will now be investigated.

Fig. 9.



Case I. Beam Supported at Both Ends and Loaded with a Uniform Load of w per Unit Length.—It is convenient to take one of the reaction-points as the origin of co-ordinates (Fig. 9). Substituting the value of M , the expression Q may be determined, and the equations for m and $\frac{dm}{dx}$ may be expressed in terms of the arbitrary constants A and B . Then calling the span of the beam $2l$ the constants may be determined by applying the condition

$$\left. \begin{array}{l} 2 \\ 0 \end{array} \right\} \frac{dm}{dx} = 0 \quad (\text{equation } 4a)$$

The expressions for m , the bending-moment on the flange, and $\frac{dm}{dx}$, the shearing-force on the rivets, then become

$$m = \frac{p}{b} \left\{ \frac{wx}{2} (2l - x) + \frac{wl}{\gamma} e^{-\gamma x} \frac{1 + e^{-2\gamma(l-x)}}{1 - e^{-2\gamma l}} - \frac{w}{\gamma^3} \right\} \quad (5)$$

$$\frac{dm}{dx} = \frac{p}{b} \left\{ w(l-x) - wl e^{-\gamma x} \frac{1 - e^{-2\gamma(l-x)}}{1 - e^{-2\gamma l}} \right\} \quad (5a)$$

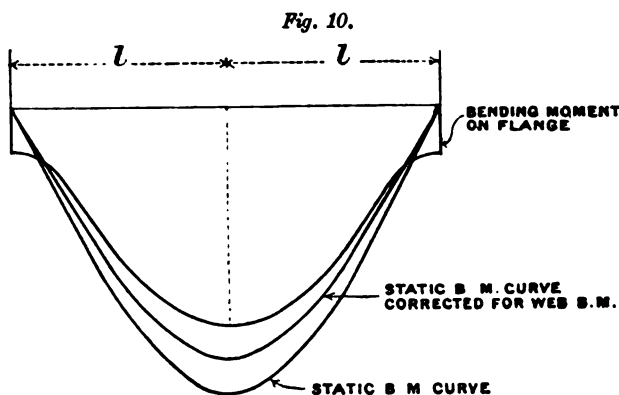
The actual proof of these equations is given in Appendix I.

These expressions are quite reasonable in form. The quantity $\frac{p}{b}$ has the value

$$\frac{p}{b} = \frac{1}{1 + \frac{I_w}{I_f}} \quad (\text{equations 3 and 3a})$$

and is a coefficient which reduces the bending-moment by the amount taken by the web. The first terms inside the brackets are the static bending-moment and shearing-force respectively, calculated from the loading in the ordinary way. The remaining terms represent the correction due to the flexibility or sliding-action of the flange-web connection.

The curves for the foregoing equations are plotted in *Figs. 10*



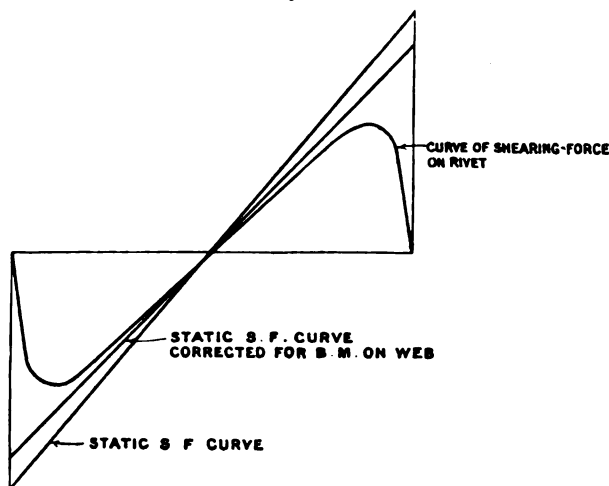
and 11. Considering the shearing-force curve (*Fig. 11*), it is apparent that the shearing-force sustained by the rivet-line is zero at the abutments, and attains a maximum at some distance from the abutments. From the equation for $\frac{dm}{dx}$, it is evident that the curve of shearing-force on the rivet-line lies inside the curve of static

ing-force, even when the latter is corrected by the ratio $\frac{p}{b}$.

The curve of shearing-force on the rivet-line is of course symmetrical about the centre of the beam.

Considering the bending-moment curves similarly in relation to the curve corrected for bending-moment taken by the web, a somewhat different state of affairs results. At the abutment the stress in the flange does not vanish, but there is a kind of initial stress of like sign to those caused by the static bending-moment. That is to say, there is initial compression in the top flange and tension in the lower flange. At the abutment, therefore, there are bending-stresses in the web, of opposite sign to those caused by the static bending-moment. These stresses in the web decrease until at a short distance from the reaction-point there are actually no

Fig. 11.



bending-stresses in the web. From this point up to the centre there are stresses in both the flange and web, of like sign, viz., of the same sign as the stresses due to the static bending-moment. An important point, however, is that the flange bending-moment curve lies inside the corrected static bending-moment curve for all points between the sections above referred to, where the web takes no bending-moment. The consequence of this is that the web takes a greater share of the bending-moment than that due to its position as part of a continuous section. From these considerations it appears that the web is always more severely strained than the flanges. The magnitude of these effects depends principally upon the magnitude of the constant γ and also upon the value of l . In

order to examine the considerations tending to exaggerate or to diminish these effects, it will be advantageous to simplify the foregoing expressions for m and $\frac{dm}{dx}$ by approximations. The value of γ in inch units will usually lie between 0.1 and 1.0; hence $l\gamma$ will be greater than 6 for a 10-foot girder. Generally, therefore, $e^{-\gamma l}$ will be small compared with $e^{\gamma l}$, and may be neglected in comparison.

Considering first the bending-moment on the web, which for any section will be $M - m$, the maximum value evidently occurs at the centre, and is

$$m_1 = \left(1 - \frac{p}{b}\right) \frac{wl^2}{2} + \frac{p}{b} w \left(\frac{1}{\gamma^2} - \frac{l}{\gamma} \frac{2e^{-\gamma l}}{1 - e^{-2\gamma l}} \right)$$

which is obtained by putting x equal to l in the expression for M and m . Substituting an approximate value for the exponential portion of the expression, the following value is obtained:—

$$m_1 = \left(1 - \frac{p}{b}\right) \theta_1 \frac{wl^2}{2},$$

where
$$\theta_1 = 1 + \frac{p}{b - p} \cdot \frac{2}{l^2 \gamma^2}.$$

But the bending-moment $\left(1 - \frac{p}{b}\right) \frac{wl^2}{2}$ is that portion of the bending-moment which is carried by the web in an equivalent beam of continuous section, and would give bending-stresses in the web equal to those in the flange. Hence the quantity θ_1 represents the increase in these stresses and is always greater than unity. Substituting values for the quantities in θ_1 the expression becomes

$$\theta_1 = 1 + \frac{12 R}{l^2 \lambda} \frac{A_f^2}{A_w + 6 A_f} \quad \dots \quad (6)$$

where A_f is the area of one flange and A_w the area of the web.

Considering a section near an abutment, the value for the bending-moment on the web becomes approximately

$$m_1 = -\frac{p}{b} \frac{l}{\gamma} w,$$

or, expressing it as a multiple of the maximum bending-moment carried by the web in an equivalent beam of continuous section, the coefficient becomes

$$m_1 = \left(1 - \frac{p}{b}\right) \theta_2 \frac{wl^2}{2},$$

where
$$\theta_2 = \frac{p}{b - p} \cdot \frac{2}{\lambda l}.$$

Substituting the values of the variables,

$$\theta_2 = \frac{12}{l} \sqrt{\frac{R A_f}{\lambda A_w}} \sqrt{\frac{A_f A_w}{A_w + 6}} \cdot \cdot \cdot \cdot \cdot \quad (7)$$

Hence these two equations (6) and (7) give approximately the increase in the bending-moment on the web over the maximum bending-moment carried by the web of an equivalent beam of continuous section. These coefficients θ therefore represent the increase of the bending-stresses in the web over the maximum bending-stress allowed in the flange. The bending-stresses in the web may have the greatest numerical value either at the centre of the span or at the abutment, depending upon whether θ_1 or θ_2 is the greater. The ratio of θ_1 to θ_2 will increase with the span, web-area and rivet-area, and will decrease as the flange-area increases and as the constant R increases. Some idea of the conditions may be obtained from the relation

$$\frac{\theta_1}{\theta_2} = \frac{l}{2 A_f} \sqrt{\left(\frac{\lambda}{R} \frac{A_w}{6} \right)},$$

which is approximately true when the flange-area is not much less than the web-area. This extra bending-stress on the web is in both cases greatest for short spans, increases as the flange-area increases, and depends on the value of $\frac{R}{\lambda}$.

Considering the effect of the $\frac{d m}{d x}$ curve upon the rivet-line, it is necessary to investigate the position of maximum stress. Maximum shearing-force on the rivet-line no longer occurs at the abutment, but at distances x_1 and x_2 from the origin. The values of x_1 and x_2 are determined by equating $\frac{d^2 m}{d x^2}$ to zero. This equation gives two real roots, x_1 and x_2 , which satisfy the equation $\frac{x_1 + x_2}{2} = l$, showing that the positions of maximum shear are at equal distances from each abutment, as might be expected. The solution of this equation is given in Appendix I, and an approximate expression for the abscissa of maximum shear is found to be

$$x_1 = \frac{l}{\gamma} \log_e l \gamma.$$

Substituting this value in the expression for the shear on the rivets, the maximum shear is found to be

$$F = \frac{p}{b} \phi w l,$$

where

$$\phi = 1 - \frac{1 + \log_e l \gamma}{l \gamma}.$$

This coefficient ϕ is always less than unity, and as $\frac{p}{b} w l$ represents the corrected value of the shearing-force on the rivets—allowing for the portion of the bending-moment carried by the web—the coefficient ϕ evidently measures the reduction due to the flexibility or sliding-action of the flange-web connection. The total reduction in the maximum static shearing-force is therefore

$$\frac{p}{b} \phi.$$

The value of ϕ decreases with l and also with γ . The value of γ is

$$\gamma = \sqrt{\frac{\lambda}{R} \left(\frac{1}{A_r} + \frac{6}{A_f} \right)},$$

and it is therefore evident that the considerations tending to increase θ , the web bending-coefficient, tend also to decrease ϕ . That is, the rivet-line is relieved of shearing-force only at the expense of increasing the bending-moment on the web.

Case II. A Beam supported at both ends and Loaded with a Single Load located at one Point in its Length.—This case is worked out in detail in Appendix II, and it is here only necessary to consider the results there obtained. The general method of obtaining the results is that already described. The equations for bending-moment in the flange and shearing-force in the rivet-line become

$$m = \frac{p}{b} \frac{g W}{f + g} \left\{ (f - x) - \frac{e^{\gamma f} e^{-\gamma x} - e^{\gamma x}}{\gamma (e^{\gamma f} + 1)} \right\}$$

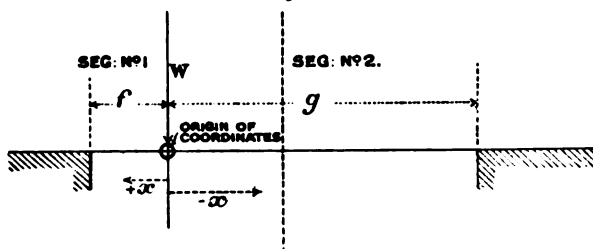
$$\frac{d m}{d x} = -\frac{p}{b} \left\{ 1 - \frac{e^{\gamma x} + e^{\gamma f} e^{-\gamma x}}{1 + e^{\gamma f}} \right\} \frac{g W}{f + g}.$$

These equations refer to segment No. 1 in *Fig. 12*; equations similar in form apply to segment No. 2. On plotting these curves (*Figs. 13 and 14*) the results are found to be somewhat similar to those obtained in the last case. The shearing-force curve $\frac{d m}{d x}$ lies

inside the corrected static shearing-force curve and attains maximum values midway between the point of application of the load and each abutment. The shearing-force on the rivet-line vanishes at the abutments and at the point of application of the load. The flange

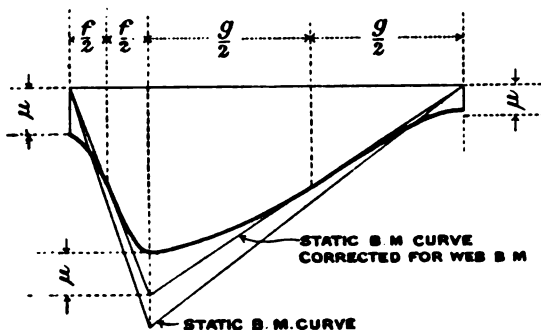
bending-moment curve crosses the corrected static bending-moment curve at points midway between the load and each abutment. Between these two points the flange bending-moment curve is inside the corrected static bending-moment curve, whilst outside these points it is outside the corrected static bending-moment curve, so that there

Fig. 12.



is initial flange bending-moment at the abutments. The difference between the flange bending-moment curve and the corrected static bending-moment curve is the extra bending-moment carried by the web in excess of the bending-moment carried due to its position as part of the section of an equivalent beam of continuous section.

Fig. 13.



This extra bending-moment attains maximum values at the abutments and at the point of application of the load, and has equal values at each of those three points in the beam; it is denoted by μ in Fig. 13, and may be expressed as

$$\mu = \frac{p}{b} M - m.$$

In Appendix II it is shown that the values of μ are identical and

maximum values at the centre and at the ends. The value of μ at these sections is

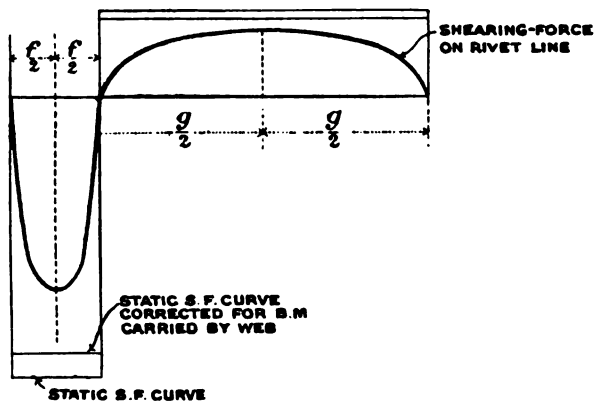
$$\mu = \frac{p}{b} \frac{g}{f+g} \frac{e\gamma f - 1}{\gamma(e\gamma f + 1)},$$

or if M_x is substituted for the value of the maximum static bending-moment

$$\mu = \frac{p}{b} \frac{M_x}{f\gamma}, \quad (\text{approx.})$$

when f is not very small. If θ is the percentage increase of

Fig. 14.



bending-moment (and consequently of stress) in the web, as in the last case, then

$$\theta = 1 + \frac{\frac{b}{p} - 1}{f\gamma} = 1 + \frac{6 A_f}{A_w f\gamma}, \quad (\text{approx.})$$

where γ has the value given in the last case, viz.,

$$\gamma = \sqrt{\frac{\gamma}{R} \left(\frac{1}{A_f} + \frac{6}{A_w} \right)},$$

and f is the distance of the load from the nearest abutment, and A_f , A_w the flange and web areas respectively.

On examining the curve of shearing-stress on the rivets, it is found that for any given position of the load the maximum shearing-force on the flange-web connection is given by

$$\text{shearing-force} = \frac{p}{b} F \phi,$$

$$\text{where} \quad \phi = 1 - 2e^{\frac{-\gamma f}{2}} \quad (\text{approx.})$$

where f is not very small. The general form for ϕ is

$$\phi = 1 - \left(\cosh \frac{\gamma f}{2} \right)^{-1};$$

hence when f is very small ϕ becomes zero. This consideration is of importance in the case of a travelling load. As a load moves from the centre to an abutment the shearing-force on the flange-web connection increases, but when the load is at the abutment the web-flange shearing-force becomes zero; hence there is a position of the load giving maximum web-flange shear $\left(\frac{dm}{dx} \right)$. The static shear is of course a maximum when the load is at an abutment. In order to find this position of the load giving maximum flange-web shear it is necessary to find the maximum value of the expression—

$$\frac{dm}{dx} = \frac{p}{b} \left(1 - \frac{1}{\cosh \frac{\gamma f}{2}} \right) \left(1 - \frac{f}{2l} \right) W,$$

and so far the Author has been unable to obtain a solution in a simple form. Taking the approximate form

$$\frac{dm}{dx} = \frac{p}{b} \left(1 - 2e^{\frac{-\gamma f}{2}} \right) \left(1 - \frac{f}{2e} \right) W$$

a maximum value is found to be

$$F_x = \frac{p}{b} \left(1 - \frac{1}{l\gamma} \right) \left(1 - \frac{1}{l\gamma} \log_e 2l\gamma \right) W,$$

but this solution probably gives a smaller value for the maximum shear than the correct value.

Effect of Riveting over the Bearing-Plate.—Reviewing the results obtained in Cases I and II it is apparent that under certain stresses and certain conditions there may be sliding of the flange-members over the web, owing to the deflection of the rivets connecting the flange and the web. For convenience of discussion a compound girder, consisting of a rolled-steel joist with a flange-plate riveted on top and bottom, will be considered, and it will be taken as supported at both ends, and loaded with a central load. The joist portion of the girder will take up a deflection-curve, the top flange being compressed

and the lower flange extended. Considering the lower flange at a position under the load, as the lower flange of the joist is extended and the flange is connected to the lower flange-plate by rivets, there is a tendency to extend the lower flange-plate. If the lower flange-plate were a portion of the joist, it would be extended according to the law which governs the extension of the lower flange of the joist. As, however, the joist and plate are connected by rivets, the rivets are stressed in order to extend the flange-plate. If, as this action goes on, the rivets deflect at all under the stress, the result is that the flange-plate is not extended as much as it would be if the joist and plate were continuous, and a portion of the strain is taken up by the rivets deflecting and a portion by the flange-plate extending; consequently the flange-plate is not stressed so much as it would be if it were continuous with the joist. Considering this action from the centre of the beam towards an abutment, it is apparent that points on the flange-plate would lag behind points on the joist which corresponded when the girder was unloaded. At the abutment, therefore, the lower flange of the joist would be stressed in compression owing to the strain in the lower flange-plate. These effects all result in altering the distribution of stress in the girder-section from that in an equivalent beam of continuous section. If the moments of the fibre-stresses in the joist, and also of those in the flange-plates, be considered as bending-moments the sum of which is equal to the static bending-moments, then it is apparent that the ratio of the bending-moments is altered. The joist bending-moment is generally increased and the flange-plate bending-moment is reduced. At the same time the stresses in the rivets are reduced. These effects are greater for riveting giving the greatest deflection under a given load, and are consequently decreased by increasing the rivet-area or by improving the quality of the riveting. There are other considerations which govern these effects, however, which have not hitherto been considered. These considerations are the connection of the web to the flanges at the abutments, outside the reactions. From the foregoing it is evident that if the girder extends at each end past the reaction there will be a certain number of rivets to secure the flange to the web, and these rivets will assist to moderate the effects above described. This will be the case whether the girder extends past the reaction or whether the reaction acts on such extension. In other words, the length of the girder over the bearing-plate will assist to secure the flange to the web. This condition of affairs will now be examined.

Case III. Distribution of Stresses in a Girder, the ends of which extend on both sides for a Distance past the Reaction.—This case

applies to girders in which the ends are treated as shown in *Fig. 15*. The full analysis of the investigation is given in Appendix III, and only the results there obtained are here considered. In the Appendix referred to, the case is investigated for any conditions of loading, but the final formulas are directly applied to a distributed load of w per unit length. All the expressions are referred to axes through one reaction. The results conclusively prove that, when the distance d is great, the maximum shearing-force on the rivet-line occurs at the abutment, and its value is half the maximum static shearing-force calculated from the loading. That maximum shearing-force occurs at the reaction when d is great is readily proved. Referring to Appendix III for the equation to the bending-moment in the flange at the bay d ,

$$m_1 = A_1 e^{\gamma x} + B_1 \gamma e^{-\gamma x};$$

hence

$$\frac{d m_1}{d x} = A_1 \gamma e^{\gamma x} - B_1 \gamma e^{-\gamma x}.$$

This expression has a maximum value when $\frac{d^2 m_1}{d x^2} = 0$,

i.e., when

$$A_1 \gamma^2 e^{\gamma x} + B_1 \gamma^2 e^{-\gamma x} = 0,$$

and

$$A_1 e^{\gamma x} + B_1 e^{-\gamma x} = 0;$$

and if the maximum value occurs when $x = 0$, the further condition for a maximum is

$$A_1 + B_1 = 0.$$

But $A_1 = B_1 e^{2\gamma d}$; hence the condition becomes

$$B_1 (1 + e^{2\gamma d}) = 0,$$

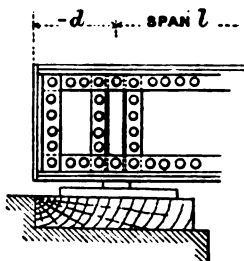
and a maximum value occurs at the reaction if $B_1 = 0$. An inspection of the value of B_1 in equation (22) shows that $B_1 = 0$ if $d = \infty$. Consequently if $d = \infty$ the maximum shearing-force occurs at the abutment, and is one-half the static shearing-force. Also in the case of $d = \infty$ it is found that the bending-moment on the flange at the abutment is

$$m_r = \frac{p w l^2}{b} \frac{\theta_1}{2}$$

where

$$\theta_1 = \frac{1}{l \gamma},$$

Fig. 15.



and at the centre of the span

$$m_c = \frac{p}{b} \frac{w l^2}{2} \theta_2,$$

where

$$\theta_2 > \left(1 - \frac{1}{l^2 \gamma^2}\right).$$

Hence when d is large, not only is the shearing-force on the rivet-line reduced to half the static value, but the bending-moment is distributed very approximately as calculated in the ordinary way, for θ_1 is always very small, and θ_2 is very approximately equal to unity; θ_1 is half the value of the corresponding coefficient for a girder without overhang. The amount of the overhang of the girder (d) cannot be made infinitely great, but an examination of the formulas shows that a relatively small amount of overhang is sufficient to distribute the stresses very approximately in the same manner as though d were infinitely great. The variation of the stresses when d is not infinitely great from those given above for $d = \infty$ may be represented by

$$\sigma = 1 - e^{-2\gamma d}.$$

Restricting the variation to 1 per cent. the condition must be that

$$e^{2\gamma d} = 100$$

$$d = \frac{2.3}{\gamma}.$$

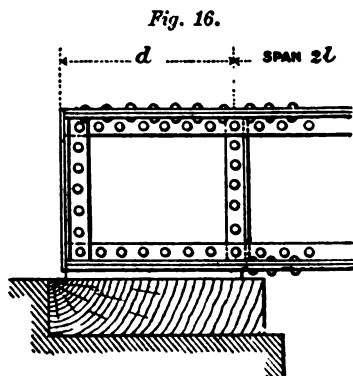
The value of γ depends on R , but taking $R = 4$ inches γ will always be less than $\frac{1}{2}$ inch; hence d will always have a reasonable value. The following are the values of γ with $R = 4$ inches, and the corresponding values of d in inches for a variation of 1 per cent.

Girder.		Value of γ in Inches.	Value of Overhang d in Inches.
Type.	Span in Feet.		
A	13.0	0.316	8
B	19.5	0.260	9
C	39.0	0.216	11
D	10.0	0.440	6
E	20.0	0.123	19
H	28.0	0.224	11
J	40.0	0.224	11
K	60.0	0.182	13
L	60.0	0.142	17

from the foregoing ideal stresses (when $d = \infty$) calculated for girders in the broad-gauge line of the Nizam's Guaranteed State Railway.

A very simple means is thus obtained whereby the shearing-stresses on the rivet-line in plate-girders may be reduced by 50 per cent., the only condition being a slight deviation from the usual construction of the bed-plates. The application of this principle will be considered later.

Case IV. Distribution of Stress in a Girder loaded uniformly and supported at each end so that the Reactions are distributed over a portion of the Length.—The case here considered is that of a girder bedded in the ordinary way, as illustrated in *Fig. 16*. The reactions are assumed to be evenly distributed over the base-plate, which is of length d . The full analysis of the case is given in Appendix IV, in which the expressions obtained are all referred to axes through the centre of the span. The results arrived at will now be considered.



The expression for the shearing-force in the rivet-line at the edge of the bed-plate when d is large, is very approximately equal to the maximum static shear.

Thus, when $x = l$,

$$\frac{d m}{d x} = \frac{p}{b} w l \left(1 - \frac{1}{2 l \gamma} \right) = \frac{p}{b} w l \text{ (nearly),}$$

so that it appears that a long base-plate has no effect in reducing the maximum rivet-shear similar to the effect observed in Case III for an overhung end. This result is not quite that which might perhaps be expected, but the rigid analysis of the conditions as given in Appendix IV appears to put the question beyond doubt. An examination of the equations of bending-moment also fails to show any considerable reduction of stresses. The expression for the bending-moment on the flange at the inside of the base-plate becomes

$$m_r = \frac{p}{b} \left\{ M_r - \frac{w}{2 \gamma^2} \right\}$$

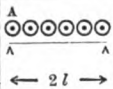
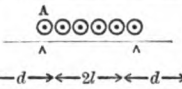
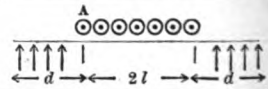
and for the bending-moment on the flange at the centre

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$$m_c = \frac{p}{b} \left\{ M_c - \frac{2}{\gamma^3} \left(1 - \frac{1}{e^{\gamma l}} \right) \right\}$$

In these equations M_r and M_c are the static bending-moments at the inside of the base-plate and at the centre of the span respectively. These bending-moments have not quite the same values as static bending-moments calculated for the reactions acting at points. The maximum flange-web shearing-stress $\left(\frac{dm}{dx} \right)$ does not occur over the edge of the bearing-plates when d is not great, and no object seems to be served by estimating the reduction in stresses due to the length of the bearing-plates. The condition assumed in deducing the formulas in this case, viz., that the reactions are evenly distributed over the bearing-plates, is rarely even approximately realized in practice, and this consideration alone would render any results obtained valueless in application to practice. In any case the alteration in stresses from those in a similar rigid beam is not very different from the stresses calculated in Case I.

In the following Table is shown a comparison of the results obtained for a uniformly-loaded beam in Cases I, III and IV. It will be observed that the expressions obtained in Cases III and IV may be converted into those obtained in Case I by putting $d=0$.

Stress.	Value of d .	CASE I.	CASE III.	CASE IV.
				
Shearing-stress on rivet-line at the point A.	$d=0$	$F=0$	$F=0$	$F=0$
	General		$F = -\frac{p}{b} \frac{wl}{2} (1 - e^{-2\gamma d})$	$F = \frac{p}{b} \left\{ 1 - \left(\frac{1}{d} + \frac{1}{l} \right) \frac{1 - e^{-2\gamma d}}{2\gamma} \right\} wl$
	$d=\infty$		$F = -\frac{p}{b} \frac{wl}{2}$	$F = \frac{p}{b} wl \left(1 - \frac{1}{2l\gamma} \right)$ $= \frac{p}{b} wl$ (nearly)
Bending-moment on flange at point A.	$d=0$	$m = \frac{p}{b} \frac{wl}{\gamma}$	$m = \frac{p}{b} \frac{wl}{\gamma}$	$m = \frac{p}{b} \frac{wl}{\gamma}$
	General		$m = \frac{p}{b} \frac{wl}{\gamma} \frac{1 + e^{-2\gamma d}}{2}$	$m = \frac{p}{b} \left[M_r - \frac{w}{2\gamma^2} \left\{ 1 + \left(1 + \frac{l}{d} \right) e^{-2\gamma d} - \frac{l}{d} \right\} \right]$
	$d=\infty$		$m = \frac{p}{b} \frac{wl}{2\gamma}$	$m = \frac{p}{b} \left\{ M_r - \frac{w}{2\gamma^2} \right\}$

Girder with two Shear-Surfaces in each Flange.—

As so far have been assumed to have, in each shear-surface, by which stress is given to the flange. As a number of shear-surfaces have to be considered in a plate-girder containing one plate in each flange, the bending-moment will be first transmitted by the rivets from the angle-bars, and then some of this bending-moment will be transmitted from the angle-bars to the plate. Thus the girder consists of two shear-surfaces, A and B, *Fig. 17*. An application of the foregoing results to such a case will imply that no slipping occurred in the web, but that the angle-bars and plate were treated as one piece of material. It will be seen later that this assumption is probably not the truth in many cases. For convenience of description, the shear-surfaces A and B will be considered as one shear-surface; there are really two surfaces, but so far as the present investigation is concerned they may be considered as one.

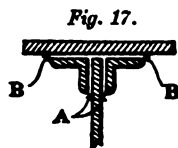


Fig. 17.

The distribution of shear in a girder of two shear-surfaces will be considered. Denoting the bending-moment transmitted by the first surface by m , and that transmitted by the second surface by n , the equations for the bending-moment in the flanges may be written

$$m = \left(\frac{p}{b}\right)_1 \left\{ A e^{rx} + B e^{-rx} + M + \left(\frac{a^1 b + a b^1}{b b^1 - c c^1} - \frac{a}{b^1} \right) 2\delta \right\}$$

$$n = \left(\frac{p}{b}\right)_2 \left\{ A e^{rx} + B e^{-rx} + M + \left(\frac{a^1 b + a b^1}{b b^1 - c c^1} \right) 2\delta \right\}$$

The shearing-force in the first line of rivets (that nearest to the web) =

$$\frac{d m}{d x} = \left(\frac{p}{b}\right)_1 \left\{ A r e^{rx} - B r e^{-rx} + F \right\}$$

The shearing-force in the second line of rivets (that furthest from the web) =

$$\frac{d n}{d x} = \left(\frac{p}{b}\right)_2 \left\{ A r e^{rx} - B r e^{-rx} + F \right\}$$

where the constants A and B are those previously calculated. It will be observed that within the limits of accuracy compatible with the assumption $s = 0$ there is no change in the shearing-force from

that calculated for a single shear-surface, except that due to the substitution of r for γ . The values of these two quantities are

$$\gamma = \left\{ \frac{\lambda}{R} \left(\frac{1}{A_f} + \frac{6}{A_w} \right) \right\}^{\frac{1}{2}}$$

$$r = \left\{ \frac{\lambda}{R} \left(\frac{2}{A_f'} + \frac{1}{A_f''} + \frac{6}{A_w} \right) \right\}^{\frac{1}{2}}$$

where A_w is the web-area, A_f the flange-area, A_f' the area of the portion of the flange between the first and second shear-surfaces, and A_f'' the area of the portion of the flange beyond the second shear-surface. In this value for r the value of λ is assumed to be the same for both rivet-lines, and in both formulas the flange-areas are assumed to be located at the extremities of the flange. From these values it would appear that the introduction of a second shear-surface increases the shearing-force on the first rivet-line, because from the foregoing values it is evident that r is always greater than γ . This indicates, for example, that a less efficient form of construction is obtained by riveting four heavy angle-bars as flanges to a web-plate than by using four light angle-bars and two light flange-plates of the same total area of cross-section. Further, the quantity $\frac{a}{b^{\frac{1}{2}}}$ measures the reduction of the total bending-moment carried by the flange due to the introduction of the second shear-surface. This quantity $\frac{a}{b^{\frac{1}{2}}}$ has the value

$$\frac{a}{b^{\frac{1}{2}}} = \frac{R}{\lambda} \frac{1}{\frac{1}{A_f'} + \frac{1}{A_f''}},$$

and it should be the object of good design to reduce it as much as possible. This is done by making $\frac{1}{A_f'} + \frac{1}{A_f''}$ large; hence A_f' and A_f'' should be small. The conclusion seems to be that the sectional areas of the flange-plates should be made as small as convenient, and the use of plates of great sectional area should be avoided.

The results of this investigation of girders of two shear-surfaces are not here directly applied to determine formulas for different cases of loading. Such formulas are readily obtained from the foregoing equations, but it is very doubtful whether they would serve any useful purpose. The formulas obtained for girders of one shear-surface afford probably as accurate an estimation of the distribution of stress as can be obtained by calculation in the manner given in this Paper. An approximation to the conditions of

stress with two shear-surfaces may be in all cases obtained by using the foregoing value of s in place of γ .

Experimental Verification of the Distribution of Stress in Riveted Girders.—The deflection of a loaded riveted girder is governed by the distribution of stress in it; any sliding-action in the web-flange connection which may occur would therefore affect the deflection-curve of the girder. In Appendix V the deflection-curve of a riveted girder is calculated for the case of a single load placed at any point in the span, and the deflection is compared with that which would be obtained if the flange-web connection were quite rigid. The measurement of the deflection-curve of a riveted girder therefore provides a method of experimentally verifying the distribution of stress in it.

Practical Applications of the Results obtained in the Foregoing Investigations.—There is usually a considerable amount of uncertainty with regard to the application to practice of results obtained by lengthy and involved mathematical reasoning. Even when the original assumptions upon which the results are based are simple and well-founded, the uncertainty still exists unless the several mathematical processes can be pictured and expressed in simple form. Usually it is necessary to base the application of the results in practice on some further evidence. This evidence may be supplied by the reasonableness of the resulting deductions, by experimental verification, or by the theory evolved supplying explanations of known effects. In the case of the present theory, the Author is fully aware that many of the long expressions obtained are quite unsuitable to be applied to actual cases occurring in practice. It is hoped, however, that the few practical results obtained, and here considered, may be sufficiently useful to warrant the agency of the somewhat clumsy mathematical machinery by which they have been obtained. Most of the results hitherto dealt with are quite reasonable, and many do not seem to require mathematical demonstration to justify them. With regard to the experimental verification of the results, it is only necessary to point out that such verification has been shown to be quite possible and not very difficult. The use of the deductions from the investigation in indicating the form which deterioration will take in girders is of importance, and affords an indication of the general accuracy of those deductions. The Author has recently had very favorable opportunities of studying the deterioration of girders, particularly in the case of a number of similar girders under the same loading and yet in widely different conditions.

Signs of deterioration are apparent in

the flanges of girders. Usually the first indication takes the form of vertical cracks in the web. When these cracks appear near the lower flange they may be sometimes ascribed to local stresses due to high bearing-stresses on the rivets. In the case of located loads badly distributed they may be ascribed to the effect of surface-loading in causing rapid variation of the shearing-stress in the web. In many cases, neither of these two explanations is sufficient justification for the appearance of web-cracks. The results of sliding in the web-flange connection, as here considered, prove with certainty that the web-member of a riveted girder is invariably subjected to greater fibre-stresses (due to bending alone) than the flanges. This would fully account for vertical web-cracks appearing near the upper flange at the abutment and near the lower flange in the neighbourhood of a concentrated load or at the centre of a span uniformly loaded. The Author is not aware whether such web-cracks have been noticed in girders near to an abutment, but it has been demonstrated that under certain circumstances (Cases I and II) high tensile stresses may occur in the web at that position. A reference to the formulas quoted in Cases I and II will show that usually these stresses are moderately low, but the occurrence of loose joints and loose rivets may materially alter the assumptions on which these formulas are based, and in consequence increase the value of the stresses so calculated.

Girder-stresses calculated according to the orthodox method give maximum rivet-shearing stress at the reactions. If slip occurs in the web-flange connection, the maximum rivet-shearing stress occurs at a certain distance from the reaction. This would lead to the conclusion that when a web-flange joint works loose, distress in the rivets would usually occur first at this position of maximum rivet-shearing. The position of maximum shear for a located load is midway between the reaction and the load; for a distributed load it is at a distance from the reaction given by the formulas in Case I,—usually about one-fifteenth of the span. In the case of a travelling load the position of maximum rivet-shear is at a distance from the abutment given by the formulas in Case II. The Author is unable to say whether generally these positions are found to be the most usual ones for loose rivets and open joints. The values are all calculated for a girder in which the reactions act through the ends of the girder.

The prime importance of the position of the resultant-lines of the reactions has been demonstrated in the consideration of Cases III and IV. The stresses in a girder bedded in the usual manner may vary to a considerable extent, due to the manner in which the bed-

blocks are fixed. If the reaction is very near the inside edge of the bearing-plate the maximum rivet-stresses may be half the stresses caused by allowing the girder to bear on the outside edges of the bearing-plate; and at the same time the web-stresses due to bending are very much reduced. A well-bedded girder in which the reactions pass through the centres of the bearing-plates would not be in as favourable a condition in respect of stresses as that in the case first noted. With the ordinary form of bearing-plate, riveted to the lower flange, applied to girders not exceeding 40 feet span, there is great uncertainty as to the position of the reaction. It is by no means an uncommon experience with girder under-bridges to find that owing to defective grouting under the bed-blocks, or to other causes, the girders are bearing on the extreme ends of the bearing-plates. Pier-copings render many under-bridges difficult to inspect, and unless such a case is discovered during a half-yearly inspection of bridges, or by the loose state of the approaches, it may remain in that condition for a considerable length of time. The use of the ordinary form of bearing-plate renders such occurrences possible, and in consequence makes it possible for girders of the same kind and under the same loading to deteriorate very differently. This consideration of the conditions of the bearings of girders yields an explanation of the unequal life and condition of the same kind of girders in railway under-bridges used with the same loads. The usual causes advanced for this, viz., the existence of curves or changes of gradient in the vicinity, frequently fail to offer a suitable explanation. Defective bridges are, as often as not, discovered on the straight and on the level, when similar bridges on curves and heavy gradients are showing no signs of distress.

The foregoing is an attempt to show that certain well-known phenomena in bridge-maintenance may be readily explained by the actions of the stresses exhibited by the expressions investigated. The application of these expressions to design will now be considered.

In examining the distribution of stress in a rivet-line it should be remembered that with new rivets, well driven, no slip of the riveted surfaces over one another takes place, provided the shearing-stress on the rivets does not exceed a certain limiting value. Up to this value the shearing-stress on the rivets is resisted solely or partly by the friction between the riveted surfaces. If this condition obtains throughout the girder, no slip occurs, and the distribution of the rivet-stresses is accurately determined from the curve of static shearing-force in the ordinary manner. If slip occurs, and only if slip occurs, the distribution of rivet-shearing stress is altered, and

rivets relieve one another of stress, at the same time altering the distribution of the stresses due to bending. It may here be noted that while the rivet-shearing stress is resisted by the frictional resistance of the joint to sliding, the bearing-stress on the rivet is not of importance. The results obtained in this investigation do not apply to girders in which the rivet-shearing stresses—calculated in the orthodox manner—are sufficiently low, and the riveting sufficiently good to allow the stresses to be taken up by the frictional resistance of the joint. The rivet-stresses of such girders require no further consideration. Provided the shearing-stresses in a girder are sufficiently high to overcome the frictional resistance of the flange-web joint, the stresses are modified by the sliding action; and the distribution is expressed by the relations obtained in this Paper. This case embraces by far the greater number of plate-girders in use, because although initially only a portion of the riveting is stressed sufficiently high—calculated by the ordinary rules—to cause “sliding,” yet the sliding of a portion of the flange would probably upset the equilibrium of the remainder until the shearing-resistance became taken up in sliding throughout the whole length. This sliding-action is by no means invariably detrimental. In the case of a girder with the reactions at the ends (which may be caused by bad bedding as previously described) the effect of sliding is to decrease the shearing-stress in the rivet but to increase the bending-stresses in the web. Sliding of the flange-web connection is undoubtedly detrimental in such cases. With the position of the reactions fixed and the girder-ends sufficiently overhung, the effect of sliding is to halve the rivet-stresses and only increase the web bending-stresses to a very slight extent. Sliding in this case in no way weakens the girder. The foregoing consideration, showing as it does that the breakdown of the frictional resistance of the riveted flange-web connection is in certain cases not detrimental, in no way diminishes the necessity of renewing loose and missing rivets in girders. Rivets that are allowed to become unduly loose, and missing rivets, cause alterations in the distribution of stresses that are not considered in deducing the alteration in the distribution due to sliding. It is therefore of the utmost importance that loose, defective, and missing rivets in girders be renewed without undue delay. The shearing-stress necessary to break down the frictional resistance of a riveted joint is not very accurately determinable; it is, however, sufficiently high to limit the sliding in most cases to the first shear-surface. In some cases, the sliding may extend to the second shear-surface. The formulas about to be quoted may still be applied in such cases, the constant γ being modified in the manner previously described when

examining sliding over two shear-surfaces. The conclusion then arrived at should be noted, viz., that in designing the flanges of girders it is well to make the elements of the flange as small as possible. Flange-plates should be made as small in section as is convenient; thus the bending-stresses in the web of a girder are reduced by using two 12-inch by $\frac{1}{2}$ -inch flange-plates in place of one 12-inch by $\frac{3}{8}$ -inch and one 12-inch by $\frac{1}{4}$ -inch plate. In a similar manner the web-stresses in a girder are reduced by substituting a plate and two small angle-bars for the flange instead of two heavy angle-bars of the same total area.

It has been shown that in no case is a bending-moment immediately transferred to an element of the flange; the bending-moment carried by the flange grows according to an exponential law. For this reason flange-plates should not be stopped short where they are no longer required as determined by the static bending-moment curve, but should be carried some distance further. This is now the practice in good construction, but the exact extra length to be given to the plate is not fixed by rule. The over-lap might, however, be fixed by a suitable empirical formula based on the equation

$$x = \frac{1}{y} \log_e l r \text{ (in Case I), such as}$$

$$\text{over-lap} = 10 \log 8 l \text{ inches,}$$

where l is the calculated length of the plate in feet. Strictly, the over-lap should also depend on the sectional area of the plate, the ratio of the added area to that of the remainder of the flange, and the rivet-area per foot connecting the added plate to the flange. The most important application of the results of these investigations has yet to be considered, viz., the calculation of the actual rivet-stresses in riveted girders. As previously mentioned, the cases of girders subjected to low rivet-stresses are not here considered. The results of Cases III and IV show that the rivet-stresses depend on the form of the bearing of the girder on the abutment. In the case of girders in which the bearing is, or is liable to be, very near to the end of the girder, the results of Cases I and II apply; that is, the web bending-stresses are increased in the ratios there given. The rivet-stresses are slightly less than the values calculated by the ordinary method, the reduction-ratios being also given. It follows from this that it is very disadvantageous to design riveted girders so that the reactions are liable to act through the ends. In some cases it may be impossible to avoid doing so, as for example, in the case of a plate-girder fixed to the side of a stanchion. In such cases the riveting should be designed to take the stresses calculated by the

ordinary method, and the maximum flange bending-stresses should be so reduced that the increased bending-stress in the web, estimated by the methods given in Cases I and II, is within safe limits. Plate-girders, the ends of which are unrestricted, should be so designed that the line of action of the reaction is fixed. The ends should then be overhung by an amount d (Fig. 18) determined by the formula

$$d = \sqrt{\frac{\lambda}{R} \left(\frac{1}{A_f} + \frac{6}{A_w} \right)} \text{ inches,}$$

where λ is the rivet-area per lineal inch of flange,

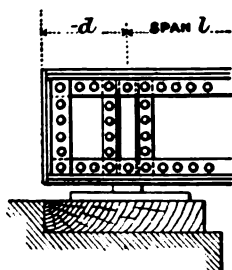
A_f the flange-area,

A_w the web-area,

and R a constant, about 4 inches.

With this condition satisfied, the maximum rivet-stress is very approximately half that due to maximum static shear, and the bending-stresses in the web are not sensibly greater than the flange-stresses. With the foregoing value for d this should be true to 1 per cent. as shown in Case III. This supplies a means of ensuring that the rivet-stresses in girders shall be reasonably low. In the case of girders already constructed and under load, some modification of the bearing-plates such as that suggested above will ensure that the rivet-stresses are half those calculated by the ordinary method, and will consequently prevent any damage to the

Fig. 18.



riveting which might result from the line of the reaction moving near to the end.

The Author desires to express his indebtedness to Mr. Ralph Freeman, Stud. Inst. C.E., for suggestions upon which this investigation is based ; to Mr. J. E. Martin, Assoc. M. Inst. C.E., the late Officiating Chief Engineer, Nizam's Guaranteed State Railway, for allowing certain tests to be carried out on full-size girders ; and to Mr. C. T. Walker, B.Sc., Assoc. M. Inst. C.E., for assistance rendered by plotting some of the stress-curves and in connection with the above-mentioned tests.

The Paper is accompanied by diagrams, from which the Figures in the text have been prepared ; and by the following Appendixes.

[APPENDIXES.]

APPENDIXES.

APPENDIX I.

DETERMINATION OF THE DISTRIBUTION OF STRESSES IN A PLATE-GIRDER OF CONSTANT SECTION WHEN LOADED UNIFORMLY THROUGHOUT ITS LENGTH AND SUPPORTED AT EACH END.

Expression for total Bending-Moment.—Let w denote the intensity of load per unit length and $2l$ the effective span, with axes through one reaction

$$M = \frac{wx}{2}(2l - x); \quad \frac{dM}{dx} = w(l - x).$$

Determination of Q:—

Let $Q = Ax^2 + Bx + C$, then $\frac{d^2Q}{dx^2} = 2A$;
substituting in the general equation

$$a \frac{d^2m}{dx^2} - bm = -pM \quad (21 \text{ A})$$

$$2Aa - bAx^2 - Bbx - bC = -\frac{pw}{2}x(2l - x)$$

$$A = -\frac{pw}{2b}$$

$$B = \frac{p}{b}wl$$

$$C = -\frac{ap}{b^2}w;$$

hence $Q = -\frac{pw}{b}\left(\frac{x^2}{2} - lx + \frac{a}{b}\right).$

Form of "m."—Substituting in equation (4)

$$m = A \cosh \gamma x + B \sinh \gamma x - \frac{pw}{b}\left(\frac{x^2}{2} - lx + \frac{a}{b}\right)$$

$$\frac{dm}{dx} = \gamma(A \sinh \gamma x + B \cosh \gamma x) - \frac{pw}{b}(x - l).$$

Determination of Constants A and B.—Applying equation (4a)

$$\left| \frac{dm}{dx} \right|_0^{2l} = 0$$

$$x = 0; \quad \frac{dm}{dx} = B\gamma + \frac{pw}{b}l = 0$$

$$\therefore B = -\frac{p}{b\gamma}wl$$

$$x = 2l; \quad \frac{dm}{dx} = \gamma(A \sinh 2\gamma l + B \cosh 2\gamma l) - \frac{pw}{b}l = 0$$

$$\therefore A = \frac{pw}{b\gamma} \cdot \frac{1 + \cosh 2\gamma l}{\sinh 2\gamma l};$$

$$\text{hence } A = \frac{pw}{b\gamma} \frac{1 + e^{-2\gamma l}}{1 - e^{-2\gamma l}}.$$

Final Equations for the Distribution of Stress.—Substituting the values A and B and the function Q in equation (4)

$$m = \frac{p}{b\gamma} w l \left\{ \frac{1 + e^{-2\gamma l}}{1 - e^{-2\gamma l}} \cosh \gamma x - \sinh \gamma x \right\} - \frac{p}{b} w \left(\frac{x^2}{2} - lx + \frac{a}{b} \right)$$

$$\frac{dm}{dx} = \frac{p}{b} w l \left\{ \frac{1 + e^{-2\gamma l}}{1 - e^{-2\gamma l}} \sinh \gamma x - \cosh \gamma x \right\} - \frac{p}{b} w (x - l).$$

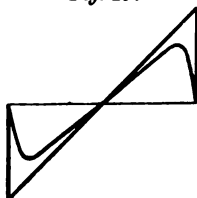
The expression for m represents the distribution of stress in the flanges, and the expression $\frac{dm}{dx}$ represents the distribution of shearing-stress along the line of rivets. It will be convenient to substitute exponential expressions for the hyperbolic functions, and generally to rearrange the form. The expressions then become:—

$$m = \frac{p}{b} \left\{ \frac{wx}{2} (2l - x) + \frac{wl}{\gamma} e^{-\gamma x} \frac{1 + e^{-2\gamma(l-x)}}{1 - e^{-2\gamma l}} - \frac{wa}{b} \right\} \quad (5)$$

$$F = \frac{p}{b} \left\{ w(l - x) - wl e^{-\gamma x} \frac{1 + e^{-2\gamma(l-x)}}{1 - e^{-2\gamma l}} \right\} \quad (5a)$$

As a check on these equations the values 0, l , $2l$ may be substituted for x in equation (5a). It is then evident that in each case $F = 0$; hence the shearing-stress curve for the rivets lies inside the static shearing-force curve as shown in Fig. 19.

Fig. 19.



Maximum Shear in Rivets.—It will be of interest to find the maximum shear in the rivet-line. The position of maximum shear is found by putting $\frac{dF}{dx} = 0$.

$$\text{Then } \frac{dF}{dx} = \frac{p}{b} \left\{ -w + wl\gamma e^{-\gamma x} \frac{1 + e^{-2\gamma(l-x)}}{1 - e^{-2\gamma l}} \right\} = 0;$$

$$\text{hence } e^{-2\gamma l} e^{2\gamma x} - \frac{1 - e^{-2\gamma l}}{l\gamma} e^{\gamma x} + 1 = 0.$$

$$\text{Putting } \alpha = \frac{e^{-2\gamma l} - 1}{2l\gamma} \quad \beta = e^{-\gamma l} \left\{ \begin{array}{l} e^{\gamma x} = \alpha \pm (\alpha^2 - \beta^2)^{\frac{1}{2}} \end{array} \right\} \quad (8)$$

In order to check this last result it is necessary to consider the value of the mean of the two roots. From consideration of the symmetry of the case the mean should be equal to l

$$\begin{aligned} \frac{x_1 + x_2}{2} &= \frac{1}{2\gamma} \left\{ \log_e (\alpha + (\alpha^2 - \beta^2)^{\frac{1}{2}}) + \log_e (\alpha - (\alpha^2 - \beta^2)^{\frac{1}{2}}) \right\} \\ &= \frac{1}{2\gamma} \log_e \{ (\alpha + (\alpha^2 - \beta^2)^{\frac{1}{2}}) (\alpha - (\alpha^2 - \beta^2)^{\frac{1}{2}}) \} \\ &= \frac{1}{2\gamma} \log_e (\alpha^2 - (\alpha^2 - \beta^2)) = \frac{1}{2\gamma} \log_e \beta^2 = \frac{2\gamma l}{2\gamma} \\ &= l. \end{aligned}$$

Thus so far the equations (5) have satisfied the tests.

Approximate Values for F, "m," &c.—When x is small compared with l the quantity $e^{-l\gamma}$ becomes very small relative to $e^{l\gamma}$.

The modified values of the expressions when x is small compared with l become

$$F = \frac{p}{b} w \{ l (1 - e^{-\gamma x}) - x \} \quad (9)$$

The ordinate of maximum shear F_x (equation 8) is approximately

$$x = \frac{1}{\gamma} \log_e l \gamma \quad (10)$$

$$F_x = \frac{p}{b} w \left\{ l - \frac{1}{\gamma} (1 + \log_e l \gamma) \right\} \\ = \frac{p}{b} \phi w l, \text{ where } \phi = 1 - \frac{1 + \log_e l \gamma}{l \gamma} \quad (11)$$

Owing to the flexibility of the web-flange connection the stresses in the web may exceed those in the flange. An approximate idea of the increase in the web-stresses may be easily obtained. The maximum stress due to bending will occur when the shearing-stress is zero; this occurs at the centre and ends of the span.

At the Centre of the Span:—

$m'_c = M - m$. Substituting in equation (5), putting $x = l$

$$= \frac{b-p}{b} \frac{w l^2}{2} + \frac{p}{b} w \left\{ \frac{a}{b} - \frac{l}{\gamma} \frac{2e^{-\gamma l}}{1 - e^{-2\gamma l}} \right\}$$

Dividing numerator and denominator of the fraction by $e^{-\gamma l}$ and neglecting $e^{-l\gamma}$ compared with $e^{l\gamma}$

$$m'_c = \frac{b-p}{b} \frac{w l^2}{2} + \frac{p}{b} \frac{w}{\gamma^2} (1 - 2l\gamma e^{-l\gamma}) \quad (12)$$

$$= \frac{b-p}{b} \theta \frac{w l^2}{2} \quad (13)$$

Where $\theta = 1 + \frac{2p}{b-p} \frac{1 - 2l\gamma e^{-l\gamma}}{l^2 \gamma^2}$ (13a)
 $= 1 + \frac{p}{b-p} \frac{2}{l^2 \gamma^2} \text{ (approx.)}$

At the Reaction:—

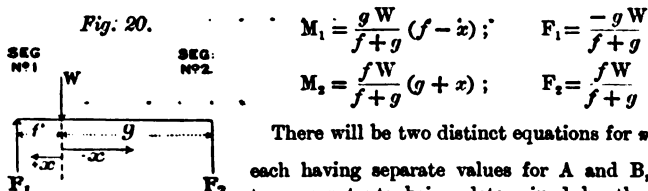
$m'_r = w \left(\frac{a}{b} - \frac{l}{\gamma} \right) \frac{p}{b}$, from (5), putting $M = 0$ and $x = 0$

$$= \frac{p}{b} \frac{w}{\gamma^2} (1 - l\gamma) = -\frac{p}{b} \frac{l}{\gamma} w \text{ (approx.)} \quad (14)$$

APPENDIX II.

DETERMINATION OF THE DISTRIBUTION OF STRESSES IN A PLATE-GIRDER OF CONSTANT SECTION, SUPPORTED AT EACH END, THE LOAD BEING CONCENTRATED AT ONE POINT.

Taking axes through the point of application of W (Fig. 20)—



$\left. \frac{dm}{dx} \right|_{x_0}^{x_1} = 0$. It is necessary in the first instance to obtain the equation for $\frac{dm}{dx}$ only. In this equation the complementary function becomes

$$Q' = \frac{p}{b} F,$$

where F assumes the values F_1 and F_2 for the several equations. Using the exponential form of equation (4) for convenience, and considering the $\frac{dm_1}{dx}$ equation

$$\frac{dm_1}{dx} = \gamma A e^{\gamma x} - \gamma B e^{-\gamma x} + \frac{p}{b} F_1.$$

Taking the limits for the equation for segment No. 1 to be f and 0,

$$\gamma A e^{\gamma f} - \gamma B e^{-\gamma f} = \frac{p}{b} \frac{gW}{f+g}$$

$$\gamma A - \gamma B = \frac{p}{b} \frac{gW}{f+g};$$

hence

$$\gamma A = \frac{p}{b} \frac{gW}{f+g} \frac{1}{1 + e^{\gamma f}}$$

and

$$-\gamma B = \frac{p}{b} \frac{gW}{f+g} \left(\frac{e^{\gamma f}}{1 + e^{\gamma f}} \right).$$

The general equation for segment No. 1 then becomes

$$\frac{dm_1}{dx} = -\frac{p}{b} \left\{ 1 - \frac{e^{\gamma x} + e^{\gamma f} e^{-\gamma x}}{1 + e^{\gamma f}} \right\} \frac{gW}{f+g}$$

By symmetry the equation for segment No. 2 becomes

$$\frac{dm_2}{dx} = \frac{p}{b} \left\{ 1 - \frac{e^{\gamma x} + e^{-\gamma g} e^{-\gamma x}}{1 + e^{-\gamma g}} \right\} \frac{fW}{f+g}$$

. . . . (15)

Examination of the Equations (15).—On substituting values $x = 0$ and $x = f$ in the equation for segment No. 1, values $\frac{d m_1}{d x} = 0$ are obtained for both substitutions.

Similarly values $x = 0$ and $x = -g$ give values $\frac{d m_2}{d x} = 0$ in the equation for segment No. 2.

A maximum value of $\frac{d m_1}{d x}$ is obtained when $(e^{\gamma x} + e^{\gamma f} e^{-\gamma x})$ is a minimum.

This occurs when

$$e^{\gamma x} = e^{\gamma f} e^{-\gamma x}$$

$$e^{2\gamma x} = e^{\gamma f}; \quad x = \frac{f}{2}$$

A similar result may be obtained for segment No. 2. The curve of shearing-force taken by the flange-web connection is therefore of the form shown in Fig. 21. A zero value is obtained at three points, and a maximum for each segment in the centre of the segment. That the maximum is less than the static shear will be seen from the following.

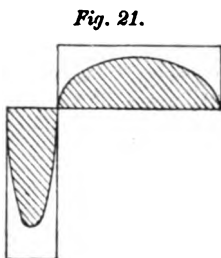


Fig. 21.

Maximum Value for Web-Flange Shear.—Substituting $x = \frac{f}{2}$ in equation (15) for segment No. 1.

$$\frac{d m_1}{d x} = \frac{-g W}{f + g} \frac{p}{b} \left\{ 1 - \frac{2 e^{\frac{\gamma f}{2}}}{1 + e^{\gamma f}} \right\} = -\frac{p}{b} F \left\{ 1 - \left(\cosh \frac{\gamma f}{2} \right)^{-1} \right\} = \frac{p}{b} \phi F,$$

where F is the statical shear in the segment,

and

$$\phi = 1 - \frac{2 e^{\frac{\gamma f}{2}}}{1 + e^{\gamma f}} \left. \begin{array}{l} \\ \\ \\ \end{array} \right\} \dots \dots \dots (16)$$

$$= 1 - \left(\cosh \frac{\gamma f}{2} \right)^{-1}$$

$$= 1 - 2 e^{-\frac{\gamma f}{2}} \text{ (approx.)}$$

The values given in equation (16) for the maximum web-flange shear give the maximum shear for any position of the load. There is however an important case in which it is necessary to determine the position of the load giving maximum shear. The maximum *static shear* is obtained when the load is very near to a reaction, i.e., when f is very small. This will not be the position for maximum web-flange shear, because when $f = 0$ the factor ϕ also becomes zero.

In order to find an approximate solution of this problem, put $F = \left(1 - \frac{f}{2l}\right) W$ where the span is $2l$,

and

$$\phi = 1 - \frac{2 e^{\frac{\gamma f}{2}}}{1 + e^{\gamma f}} = 1 - \frac{2 e^{-\frac{\gamma f}{2}}}{e^{-\gamma f} + 1} = 1 - 2 e^{-\frac{\gamma f}{2}} \text{ (nearly);}$$

then

$$F x = \frac{p}{b} \left(1 - 2 e^{-\frac{\gamma f}{2}} \right) \left(1 - \frac{f}{2l} \right) W.$$

For a maximum

$$\frac{p}{b} \frac{1}{W} \frac{dF}{df} = \gamma e^{\frac{-\gamma f}{2}} - \frac{1}{2l} + \frac{e^{\frac{-\gamma f}{2}}}{l} - \frac{\gamma f}{2l} e^{\frac{-\gamma f}{2}} = 0$$

$$e^{\frac{-\gamma f}{2}} \left(\gamma + \frac{1}{l} - \frac{\gamma f}{2l} \right) = \frac{1}{2l}$$

The term $\frac{\gamma f}{2l}$ is small compared with γ ; hence

$$e^{\frac{-\gamma f}{2}} = \{2(l\gamma + 1)\}^{-1}; \quad f = \frac{2}{\gamma} \log_e 2(l\gamma + 1) = \frac{2}{\gamma} \log_e 2l\gamma \text{ (nearly).}$$

Substituting in the equation for F,

$$F = \frac{p}{b} \left(1 - \frac{1}{l\gamma} \right) \left(1 - \frac{1}{l\gamma} \log_e 2l\gamma \right) W \quad \dots \quad (16a)$$

Maximum Values of the Flange-Stress.—The equation for the bending-moment in the flange may be obtained by substituting the value of Q and the values of A and B already obtained in equation (4); the equation then becomes

$$m = \frac{p}{b} \frac{g}{f+g} W \left\{ (f-x) - \frac{e^{\gamma f} e^{-\gamma x} - e^{\gamma x}}{\gamma (e^{\gamma f} + 1)} \right\} \quad \dots \quad (17)$$

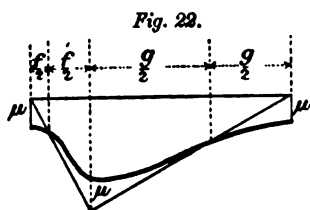
This equation is best considered as

$$m = \frac{p}{b} M - \mu \text{ where } \mu = \frac{p}{b} \frac{g}{f+g} W \frac{e^{\gamma f} e^{-\gamma x} - e^{\gamma x}}{\gamma (e^{\gamma f} + 1)} \quad \dots \quad (18)$$

The value of μ in this equation may be positive or negative, the limiting value being when

$$e^{\gamma f} e^{-\gamma x} = e^{\gamma x}, \text{ i.e., when } x = \frac{f}{2}.$$

For greater values of x , μ is negative, and must be added to the static bending-



moment; for values of x smaller than $\frac{f}{2}$,

μ is positive, and must be deducted from the bending-moment.

The $\frac{dm}{dx}$ curve becomes zero at f and 0; hence at those points the m curve has no slope, Fig. 22. The two important values for m are—

at the centre

$$\mu = \frac{p}{b} \frac{g}{f+g} W \frac{e^{\gamma} - 1}{\gamma (e^{\gamma} + 1)}; \quad m = \frac{p}{b} \frac{g}{f+g} W \left\{ f - \frac{1}{\gamma} \frac{e^{\gamma f} - 1}{e^{\gamma f} + 1} \right\} \quad \dots \quad (19)$$

at the reaction

$$\mu = -\frac{p}{b} \frac{g}{f+g} W \frac{e^{\gamma f} - 1}{\gamma (e^{\gamma f} + 1)}; \quad m = \frac{p}{b} \frac{g}{f+g} W \frac{e^{\gamma f} - 1}{\gamma (e^{\gamma f} + 1)} \quad \dots \quad (20)$$

Thus it is seen that μ is the same in both cases, and that at the centre $m = \frac{p}{b} M - \mu$, whereas at the end $m = -\mu$.

In this Appendix only the equation for segment No. 1 has been considered; similar results would be obtained for the other segment.

APPENDIX III.

- DISTRIBUTION OF STRESS IN A GIRDER EXTENDING ON BOTH SIDES OF THE REACTIONS.

It is assumed that the girder is supported at both ends and loaded in any manner whatsoever between the reactions. The portion of the girder overhanging each reaction will assist in distributing the bending-moment to the flange.

Fig. 28.

The diagram shows a horizontal line representing a girder. Below the line, there are two points labeled 'C' and 'D'. Between 'C' and 'D', there are eight small circles, each with a dot in the center, representing loads. The first circle is labeled 'A' above it, and the last circle is labeled 'B' above it. The girder extends slightly beyond the first and last circles.

It is assumed that the overhang is the same at both ends. The overhang being d and the span $2l$ with axes taken through the reaction A (Fig. 28), the equations for m may be written down.

From the general equation (4)

$$m_1 = A_1 e^{\gamma x} + B_1 e^{-\gamma x} \quad (\text{from C to A})$$

$$m_2 = \frac{p}{h} \left\{ A_2 e^{\gamma x} + B_2 e^{-\gamma x} + \frac{a}{h} w - M \right\} \text{ (from A to B)}$$

$$m_2 = A_2 e^{\gamma x} + B_2 e^{-\gamma x} \text{ (from B to D).}$$

Conditions

$$\left| \frac{dm_1}{dx} = 0 \right. \quad A_1 = B_1 e^{2\gamma d} \quad . \quad . \quad . \quad . \quad . \quad (i)$$

$$\left. \frac{d m_2}{d x} \right|_{2l+d} = 0 \quad A_2 = B_2 e^{-2\gamma(2l+d)} \quad . \quad . \quad . \quad (ii)$$

$$\left. \frac{dm_1}{dx} \right|_0 = \left. \frac{dm_2}{dx} \right|_0 \quad A_1 - B_1 = \frac{p}{b} \left(A_2 - B_2 - \frac{F_0}{\gamma} \right) \quad . \quad . \quad . \quad (iii)$$

$$\left| \frac{dm_2}{dx} \right|_{2l} = \left| \frac{dm_3}{dx} \right|_{2l} \quad A_2 e^{2l\gamma} - B_2 e^{-2l\gamma} = \frac{p}{b} \left(A_2 e^{2l\gamma} - B_2 e^{-2l\gamma} - \frac{F_2 l}{\gamma} \right) \quad (iv)$$

$$A_1 + B_1 = \frac{p}{b} \left(A_2 + B_2 + \frac{a}{b} w \right) \quad . \quad . \quad . \quad (v)$$

$$\left| \begin{matrix} m_2 \\ 2l \end{matrix} \right| = \left| \begin{matrix} m_2 \\ 2l \end{matrix} \right| \quad A_2 e^{2l\gamma} + B_2 e^{-2l\gamma} = \frac{p}{b} \left(A_1 e^{2l\gamma} + B_1 e^{-2l\gamma} + \frac{aw}{b} \right) \quad (\text{vi})$$

From these equations the constants $A_1, B_1, \dots$ may be eliminated. As it is only required to investigate the distribution of stress near the reaction A the constants required are A_1 and B_1 . In the foregoing it is assumed that the function Q is $\left(\frac{a}{b} w - M\right)$; the values of w and M depend on the distribution of the load, but this form is used on account of the application to a distributed load.

Elimination of constants.

$$2 A_2 e^{2l\gamma} = \frac{p}{b} \left\{ 2 A_2 e^{2l\gamma} - \frac{F_{21}}{\gamma} + \frac{a}{b} w \right\} \quad \dots \dots \dots (iv) + (vi)$$

$$A_2 e^{2l\gamma}(1 - e^{2l\gamma}) = \frac{p}{b} \left\{ A_2 e^{2l\gamma} - B_2 e^{-2l\gamma} - \frac{F_{21}}{\gamma} \right\} \quad \text{. . . . (ii) + (iv)}$$

By subtraction

$$\left\{ 2 A_1 e^{2l\gamma} - \frac{F_{2l}}{\gamma} + \frac{aw}{b} \right\} (1 - e^{2l\gamma}) = 2 \left\{ A_2 e^{2l\gamma} - B_2 e^{-2l\gamma} - \frac{F_{2l}}{\gamma} \right\} \quad (\text{vii})$$

$$2 B_1 = \frac{p}{b} \left\{ 2 B_2 + \frac{F_0}{\gamma} + \frac{aw}{b} \right\} \quad \therefore B_2 = \frac{b}{p} B_1 - \frac{1}{2} \frac{F_0}{\gamma} - \frac{1}{2} \frac{aw}{b} \quad . \quad . \quad (\text{iii}) - (\text{v})$$

$$2 A_1 = \frac{p}{b} \left\{ 2 A_2 - \frac{F_0}{\gamma} + \frac{aw}{b} \right\} \quad \therefore A_2 = \frac{b}{p} A_1 + \frac{1}{2} \frac{F_0}{\gamma} - \frac{1}{2} \frac{aw}{b} \quad . \quad . \quad (\text{iii}) + (\text{v})$$

By substitution in (vii)

$$\begin{aligned} \left\{ \frac{b}{p} A_1 + \frac{1}{2} \frac{F_0}{\gamma} - \frac{1}{2} \frac{aw}{b} \right\} \left\{ 2 e^{2l\gamma} (1 - e^{2\gamma d}) + 2 e^{2l\gamma} \right\} + 2 e^{-2l\gamma} \left\{ \frac{b}{p} B_1 - \frac{1}{2} \frac{F_0}{\gamma} - \frac{1}{2} \frac{aw}{b} \right\} \\ = \left\{ \frac{F_{2l}}{\gamma} - \frac{aw}{b} \right\} (1 - e^{2\gamma d}) - 2 \frac{F_{2l}}{\gamma} \end{aligned}$$

Substituting the value of A_1 from (i)

$$\begin{aligned} (e^{-2\gamma l} - e^{2\gamma(l+d)}) B_1 = \frac{1}{2} \frac{p}{b} \left\{ \frac{F_0}{\gamma} (e^{2\gamma(l+d)} + e^{-2l\gamma}) - \frac{F_{2l}}{\gamma} (1 + e^{2\gamma d}) \right. \\ \left. - \frac{aw}{b} (e^{2\gamma(l+d)} - e^{-2l\gamma} - e^{2\gamma d} + 1) \right\} \quad . \quad . \quad . \quad (21) \end{aligned}$$

Approximate value of B_1

$$2 \frac{p}{b} B_1 = (1 + e^{-2\gamma d}) e^{-2\gamma(l+d)} \frac{F_{2l}}{\gamma} - \frac{F_0}{\gamma} e^{-2\gamma d} + \frac{aw}{b} e^{-2\gamma d} \text{ nearly} \quad . \quad (21a)$$

$$= \left(\frac{aw}{b} - \frac{F_0}{\gamma} \right) e^{-2\gamma d} \text{ (approx.)} \quad . \quad . \quad . \quad (21b)$$

Equation for bending-moment and shear near an abutment.

When x is limited between 0 and $-d$

$$\begin{aligned} m &= B_1 (e^{2\gamma d} e^{\gamma x} + e^{-\gamma x}) \\ &= \frac{p}{b} \frac{1}{2} \left(\frac{w}{\gamma^2} - \frac{F_0}{\gamma} \right) (e^{\gamma x} + e^{-\gamma(2d+x)}) \quad . \quad . \quad . \quad (22) \end{aligned}$$

When $x = -d$

$$m = \frac{p}{b} \frac{1}{2} \left(\frac{w}{\gamma^2} - \frac{F_0}{\gamma} \right) (e^{-\gamma d} + e^{-\gamma d}) = \frac{p}{b} e^{-\gamma d} \left(\frac{w}{\gamma^2} - \frac{F_0}{\gamma} \right).$$

When $x = 0$

$$\begin{aligned} m &= \frac{p}{b} \frac{1 + e^{-2\gamma d}}{2} \left(\frac{w}{\gamma^2} - \frac{F_0}{\gamma} \right) \\ &= -\frac{p}{b} \frac{1 + e^{-2\gamma d}}{2} - \frac{wl}{\gamma} \text{ (nearly, for a distributed load).} \end{aligned}$$

Similarly by differentiation

$$\frac{dm}{dx} = \frac{p}{b} \frac{e^{\gamma x} - e^{-\gamma(2d+x)}}{2} \left(\frac{w}{\gamma} - F_0 \right) \quad . \quad . \quad . \quad (22a)$$

When $x = -d$

$$\frac{dm}{dx} = 0.$$

When $x = 0$

$$\begin{aligned}\frac{dm}{dx} &= \frac{p}{b} \frac{1 - e^{-2\gamma d}}{2} \left(\frac{w}{\gamma} - F_s \right) \\ &= \frac{p}{b} \frac{1 - e^{-2\gamma d}}{2} w l \text{ (for a distributed load).}\end{aligned}$$

On examination of these results it is evident that they consist of two terms, one of which is the result obtained in Case I, and the other a modifying term due to the effect of the length of the girder d . Thus in Case I the following equations were obtained for $x = 0$ —

$$F = 0 \qquad m = -\frac{p}{b} \frac{w l}{\gamma} \text{ (equation 14).}$$

From equation (22), where $x = 0$, the following equations are obtained—

$$\begin{aligned}\text{\textit{d} small, } F &= 0 & m &= -\frac{p}{b} \frac{w l}{\gamma} \\ \text{general, } F &= -\frac{p}{b} \frac{1 - e^{-2\gamma d}}{2} w l & m &= -\frac{p}{b} \frac{w l}{\gamma} \frac{1 + e^{-2\gamma d}}{2} \\ \text{\textit{d} large, } F &= -\frac{p}{b} \frac{w l}{2} & m &= -\frac{p}{b} \frac{w l}{2\gamma}.\end{aligned}$$

The stress on the flanges at the centre of the span may be readily estimated, assuming any special form of loading. Thus, assuming the load to be uniformly distributed,

$$m_x = \frac{p}{b} \frac{1}{2} \left\{ \frac{a}{b} w (e^{-\gamma d} - 1) e^{-\gamma x} - \frac{F_s}{\gamma} (e^{-2\gamma d} + 1) e^{-\gamma x} + \frac{a}{b} w - 2M \right\} \text{ approx.}$$

and at the centre, when $x = l$

$$m_c = \frac{p}{b} \frac{1}{2} \left\{ \frac{a}{b} w (e^{-\gamma d} - 1) e^{-\gamma l} - \frac{F_s}{\gamma} (e^{-2\gamma d} + 1) e^{-\gamma l} + \frac{a}{b} w - w l^2 \right\};$$

and if d is very great

$$\begin{aligned}m_c &= \frac{p}{b} \frac{w l^2}{2} \left\{ 1 - \frac{1}{l^2 \gamma^2} + \frac{1 + l \gamma}{l^2 \gamma^2} e^{-\gamma l} \right\} \\ &= \frac{p}{b} \frac{w l^2}{2} \theta \text{ where } \theta > \left(1 - \frac{1}{l^2 \gamma^2} \right).\end{aligned}$$

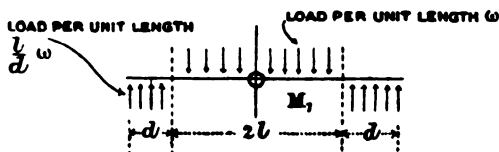
In all these expressions the values of the shearing-forces have been taken as negative when they have the same "sense" as the static shearing-force and bending-moment.

APPENDIX IV.

DISTRIBUTION OF STRESS IN A GIRDER SUPPORTED AT BOTH ENDS AND LOADED UNIFORMLY, THE REACTIONS BEING DISTRIBUTED OVER LENGTHS d AT THE ENDS OF THE GIRDER (Fig. 24).

Proceeding in a similar manner to that adopted in Appendix III, but taking the axes through the centre of the span, the following equations are obtained :—

Fig. 24.



Bending-moment equations—

$$M_1 = \frac{w}{2} \{l^2 + ld - x^2\}$$

$$M_2 = \frac{l}{d} \frac{w}{2} \{l + d - x\}^2.$$

Particular integrals—

$$a \frac{d^2 m}{dx^2} - b m = -p M.$$

Putting

$$m = A + Bx + Cx^2 = Q$$

$$a \frac{d^2 m}{dx^2} - b m = (2aC - bA) - (bB)x - (bC)x^2 = -pM;$$

hence

$$Q_1 = \frac{p}{b} \left\{ l(l+d) - 2\frac{a}{b} - x^2 \right\} \frac{w}{2},$$

and

$$Q_2 = \frac{p}{b} \left\{ (l+d)^2 + 2\frac{a}{b} - 2(l+d)x + x^2 \right\} \frac{l}{d} \frac{w}{2}.$$

General equations—

$$m_1 = \frac{p}{b} \left\{ A_1 e^{\gamma x} + B_1 e^{-\gamma x} + l(l+d) - 2\frac{a}{b} - x^2 \right\} \frac{w}{2}$$

$$m_2 = \frac{p}{b} \left\{ A_2 e^{\gamma x} + B_2 e^{-\gamma x} + (l+d)^2 + 2\frac{a}{b} - 2(l+d)x + x^2 \right\} \frac{l}{d} \frac{w}{2}.$$

$$\frac{d m_1}{dx} = \frac{p}{b} \left\{ \gamma (A_1 e^{\gamma x} - B_1 e^{-\gamma x}) - 2x \right\} \frac{w}{2}$$

$$\frac{d m_2}{dx} = \frac{p}{b} \left\{ \gamma (A_2 e^{\gamma x} - B_2 e^{-\gamma x}) - 2(l+d) + 2x \right\} \frac{l}{d} \frac{w}{2}$$

Elimination of Arbitrary Constants.—The conditions are :—

$$\left| \frac{d m_1}{dx} = 0; A_1 - B_1 = 0 \right|$$

$$\left| \frac{d m_1}{dx} = \left| \frac{d m_2}{dx}; A_1 e^{\gamma l} - B_1 e^{-\gamma l} - \frac{2l}{\gamma} = \frac{l}{d} \left(A_2 e^{\gamma l} - B_2 e^{-\gamma l} - \frac{2d}{\gamma} \right) \right|$$

$$\left| m_1 = m_2; A_1 e^{\gamma l} + B_1 e^{-\gamma l} + ld - \frac{2a}{b} = \frac{l}{d} \left(A_2 e^{\gamma l} - B_2 e^{-\gamma l} + d^2 + \frac{2a}{b} \right) \right|$$

$$\left| \frac{d m_2}{dx} = 0; A_2 e^{\gamma(l+d)} - B_2 e^{-\gamma(l+d)} = 0. \right|$$

Substituting values of B_1 and B_2 in the second and third equations

$$A_1 (e^{\gamma l} - e^{-\gamma l}) = \frac{l}{d} A_2 (1 - e^{2\gamma d}) e^{\gamma l}$$

$$A_1 (e^{\gamma l} + e^{-\gamma l}) - \frac{2a}{b} = \frac{l}{d} A_2 (1 + e^{2\gamma d}) e^{\gamma l} + \frac{2a}{b} \frac{l}{d}$$

By subtraction

$$2 A_1 (e^{\gamma(l+d)} - e^{-\gamma(l+d)}) = 2 \frac{a}{b} \left(1 + \frac{l}{d}\right) (e^{\gamma d} - e^{-\gamma d})$$

Substituting in the equation for m

$$m = \frac{p}{b} \left\{ \frac{l+d}{\gamma^2} \frac{e^{\gamma d} - e^{-\gamma d}}{d} \cdot \frac{e^{\gamma x} + e^{-\gamma x}}{e^{\gamma(l+d)} - e^{-\gamma(l+d)}} + l(l+d) - \frac{2}{\gamma^2} - x^2 \right\} \frac{w}{2}$$

$$= \frac{p}{b} \left\{ 2 \cdot \frac{l+d}{\gamma^2} \frac{\sinh \gamma d}{d} \frac{\cosh \gamma x}{\sinh \gamma(l+d)} + l(l+d) - \frac{2}{\gamma^2} - x^2 \right\} \frac{w}{2}$$

$$\frac{dm}{dx} = \frac{p}{b} \left\{ \frac{l+d}{\gamma} \frac{e^{\gamma d} - e^{-\gamma d}}{d} \frac{e^{\gamma x} - e^{-\gamma x}}{e^{\gamma(l+d)} - e^{-\gamma(l+d)}} - 2x \right\} \frac{w}{2}$$

$$= \frac{p}{b} \left\{ 2 \frac{l+d}{\gamma} \frac{\sinh \gamma d}{d} \frac{\sinh \gamma x}{\sinh \gamma(l+d)} - 2x \right\} \frac{w}{2}$$

Approximate forms for m and $\frac{dm}{dx}$, when x is large, are:—

$$m = \frac{p}{b} \left\{ \left(\frac{l+d}{\gamma^2} \frac{e^{\gamma d} - e^{-\gamma d}}{d} e^{-\gamma(l+d-x)} - \frac{2}{\gamma^2} \right) \frac{w}{2} + M_x \right\}$$

$$\frac{dm}{dx} = \frac{p}{b} \left\{ \left(\frac{l+d}{\gamma} \frac{e^{\gamma d} - e^{-\gamma d}}{d} e^{-\gamma(l+d-x)} \right) \frac{w}{2} - F_x \right\} \quad \dots (23a)$$

The following is a comparison of the bending-moment on the flanges and the shearing-force on the rivets at the abutment given by the three methods of Case I. Case III and Case IV (Appendixes I, III and IV) where M_c and M_r are the bending-moments at the centre and the inside of the base-plate respectively.

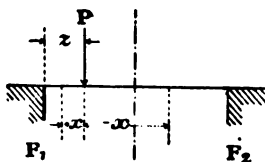
	CASE I.	CASE III.	CASE IV.
d small	$m = \frac{p}{b} \frac{wl}{\gamma}$	$m = \frac{p}{b} \frac{wl}{\gamma}$	$m = \frac{p}{b} \frac{wl}{\gamma}$
general		$m = \frac{p}{b} \frac{wl}{\gamma} \frac{1 - e^{2\gamma d}}{2}$	$m = \frac{p}{b} \left\{ M_r - \frac{w}{2\gamma^2} \left(1 + \left(\frac{l}{d} + 1 \right) e^{-2\gamma d} - \frac{l}{d} \right) \right\}$
d large		$m = \frac{p}{b} \frac{wl}{2\gamma}$	$m = \frac{p}{b} \left\{ M_r - \frac{w}{2\gamma^2} \right\}$
d small	$F = 0$	$F = 0$	$F = 0$
general		$F = -\frac{p}{b} wl \frac{1 - e^{-2\gamma d}}{2}$	$F = \frac{p}{b} wl \left\{ 1 - \left(\frac{l}{d} + 1 \right) \frac{1 - e^{-2\gamma d}}{2\gamma} \right\}$
d large		$F = -\frac{p}{b} \frac{wl}{2}$	$F = \frac{p}{b} wl \left(1 - \frac{1}{2l\gamma} \right)$ $= \frac{p}{b} wl$ (nearly)

APPENDIX V.

DEFLECTION DUE TO BENDING OF A BEAM SUPPORTED AT BOTH ENDS AND LOADED AT ANY ONE POINT (Fig. 25).

It will be advisable to derive the bending-moment equations for each side, to

Fig. 25.



avoid any error liable to occur through constructing one by analogy from the first.

$$F_1 = -\frac{2l-z}{2l} P \quad M_1 = \frac{2l-z}{2l} P(z-x)$$

$$F_2 = \frac{z}{2l} P \quad M_2 = \frac{z}{2l} P(2l-z+x)$$

$$\left. \begin{aligned} \frac{d m_1}{d x} &= A_1 \gamma e^{\gamma x} - B_1 \gamma e^{-\gamma x} - \frac{p}{b} \frac{2l-z}{2l} P \\ \frac{d m_2}{d x} &= A_2 \gamma e^{\gamma x} - B_2 \gamma e^{-\gamma x} + \frac{p}{b} \frac{z}{2l} P \end{aligned} \right\} \dots \dots \dots (24a)$$

$$\left. \begin{aligned} \int_0^z \frac{d m_1}{d x} &= 0; A_1 \gamma - B_1 \gamma - \frac{p}{b} \frac{2l-z}{2l} P = 0 \\ A_1 \gamma e^{z\gamma} - B_1 \gamma e^{-z\gamma} + \frac{p}{b} \frac{2l-z}{2l} P &= 0 \end{aligned} \right\}$$

hence $B_1 \gamma = -\frac{p}{b} \frac{2l-z}{2l} P \frac{1}{1+e^{-z\gamma}}$

and $A_1 \gamma = \frac{p}{b} \frac{2l-z}{2l} P \frac{e^{-z\gamma}}{1+e^{-z\gamma}}$

$$\left. \begin{aligned} \int_0^{z-2l} \frac{d m_2}{d x} &= 0; A_2 \gamma - B_2 \gamma + \frac{p}{b} \frac{z}{2l} P = 0 \\ A_2 \gamma e^{\gamma(z-2l)} - B_2 \gamma e^{-\gamma(z-2l)} + \frac{p}{b} \frac{z}{2l} P &= 0 \end{aligned} \right\}$$

hence $B_2 \gamma = \frac{p}{b} \frac{z}{2l} P \frac{e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}}$

and $A_2 \gamma = -\frac{p}{b} \frac{z}{2l} P \frac{1}{1+e^{-\gamma(2l-z)}}$

The equations for the bending-moment in the flanges may now be written

$$\left. \begin{aligned} m_1 &= \frac{p}{b} \frac{2l-z}{2l} P \left\{ \frac{e^{\gamma x} e^{-\gamma z} - e^{-\gamma x}}{\gamma(1+e^{-\gamma z})} + z-x \right\} \\ m_2 &= \frac{p}{b} \frac{z}{2l} P \left\{ \frac{-e^{\gamma x} + e^{-\gamma x} e^{-\gamma(2l-z)}}{\gamma(1+e^{-\gamma(2l-z)})} + 2l-z+x \right\} \end{aligned} \right\} \dots \dots \dots (24b)$$

The deflection of the web and of the flange must be the same, so that the deflection-curve may be derived from either the web bending-moment or the flange bending-moment. The deflection-curve of the flanges will be considered by putting m_1 and m_2 in the equation $I E \frac{d^2 y}{dx^2} = m$, where I is the moment of inertia of the flanges. Then by direct integration,

$$\left. \begin{aligned} I E \frac{d^2 y_1}{dx^2} &= K_1 (1 - K_2) \left(zx - \frac{x^2}{2} + \frac{e^{\gamma x} e^{-\gamma z} + e^{-\gamma x}}{\gamma^2 (1 + e^{-\gamma z})} + A_1 \right) P \\ I E \frac{d^2 y_2}{dx^2} &= K_1 K_2 \left(2lx - zx + \frac{x^2}{2} + \frac{-e^{\gamma x} - e^{-\gamma x} e^{-\gamma(2l-z)}}{\gamma^2 (1 + e^{-\gamma(2l-z)})} + A_2 \right) P \end{aligned} \right\} \quad (25)$$

and by further integration

$$\left. \begin{aligned} I E y_1 &= K_1 (1 - K_2) \left(\frac{zx^2}{2} - \frac{x^3}{6} + \frac{e^{\gamma x} e^{-\gamma z} - e^{-\gamma x}}{\gamma^2 (1 + e^{-\gamma z})} + A_1 x + B_1 \right) P \\ I E y_2 &= K_1 K_2 \left(lx^2 + \frac{x^3}{6} - \frac{zx^2}{2} + \frac{-e^{\gamma x} + e^{-\gamma x} e^{-\gamma(2l-z)}}{\gamma^2 (1 + e^{-\gamma(2l-z)})} + A_2 x + B_2 \right) P \end{aligned} \right\} \quad (26)$$

The conditions from which the arbitrary constants are determined are

$$\left. \begin{aligned} \left| \begin{array}{l} y_1 = 0 \\ y_2 = 0 \end{array} \right|_z &= \left| \begin{array}{l} y_1 = 0 \\ y_2 = 0 \end{array} \right|_0 \\ \left| \frac{dy_1}{dx} \right|_0 &= \left| \frac{dy_2}{dx} \right|_0 \end{aligned} \right\} \quad \dots \dots \dots (27)$$

These conditions give four independent equations from which A_1 , A_2 , B_1 and B_2 may be eliminated.

Elimination of Arbitrary Constants.—Substituting to obtain the equations of condition, and keeping separate the terms independent of γ , the following are obtained—

$$\frac{x^2}{3} + \frac{1}{\gamma^2} \frac{1 - e^{-\gamma z}}{1 + e^{-\gamma z}} + A_1 z + B_1 = 0 \quad \dots \dots \dots (a)$$

$$\frac{(2l-z)^2}{3} + \frac{1}{\gamma^2} \frac{1 - e^{-\gamma(2l-z)}}{1 + e^{-\gamma(2l-z)}} - A_2 (2l-z) + B_2 = 0 \quad \dots \dots \dots (b)$$

$$(1 - K_2) \left\{ -\frac{1}{\gamma^2} \frac{1 - e^{-\gamma z}}{1 + e^{-\gamma z}} + B_1 \right\} = K_2 \left\{ -\frac{1}{\gamma^2} \frac{1 - e^{-\gamma(2l-z)}}{1 + e^{-\gamma(2l-z)}} + B_2 \right\} \quad \dots \dots \dots (c)$$

$$(1 - K_2) \left(\frac{1}{\gamma^2} + A_1 \right) = K_2 \left(-\frac{1}{\gamma^2} + A_2 \right) \quad \dots \dots \dots (d)$$

For purposes of experiment it is required to obtain the value for the deflection immediately under the load, i.e., the value $\left| y_1 \right|_0$. Hence the value of B_1 is required.

$$\text{From (b) } K_2 B_2 = -\frac{(2l-z)^3}{3} K_2 - \frac{1}{\gamma^3} \frac{1-e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}} K_2 + (2l-z) A_2 K_2;$$

$$\text{from (d) } K_2 B_2 = -\frac{(2l-z)^3}{3} K_2 - \frac{1}{\gamma^3} \frac{1-e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}} K_2 + (2l-z)(1-K_2) \left(\frac{1}{\gamma^3} + A_1 \right) + \frac{K_2}{\gamma^3} (2l-z)$$

and from

$$(a) K_2 B_2 = -\frac{(2l-z)^3}{3} K_2 - \frac{K_2}{\gamma^3} \frac{1-e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}} + \frac{K_2 (2l-z)}{\gamma^3} + \frac{1-K_2}{\gamma^3} (2l-z) + (1-K_2) \frac{2l-z}{z} \left(-\frac{z^3}{3} - \frac{1}{\gamma^3} \frac{1-e^{-\gamma z}}{1+e^{-\gamma z}} - B_1 \right).$$

Substituting in (c)

$$\begin{aligned} (1-K_2) \left(1 + \frac{2l-z}{z} \right) B_1 &= K_2 \left\{ -\frac{2}{\gamma^3} \frac{1-e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}} - \frac{(2l-z)^3}{3} + \frac{(2l-z)}{\gamma^3} \right\} \\ &\quad + (1-K_2) \left\{ \left(1 - \frac{2l-z}{z} \right) \frac{1}{\gamma^3} \frac{1-e^{-\gamma z}}{1+e^{-\gamma z}} + \frac{2l-z}{\gamma^3} - \frac{z^3}{3} (2l-z) \right\} \\ \frac{2l}{z} (1-K_2) B_1 &= K_2 \left\{ -\frac{2E_2}{\gamma^3} + \frac{2l-z}{\gamma^3} - \frac{(2l-z)^3}{3} \right\} + (1-K_2) \left\{ -\frac{(l-z)}{\gamma^3} E_1 \right. \\ &\quad \left. + \frac{2l-z}{\gamma^3} - \frac{z^3}{3} (2l-z) \right\} \\ B_1 &= \frac{z^3}{2l(2l-z)} \frac{(2l-z)\gamma - 2E_2}{\gamma^3} - \frac{z^3}{6l} (2l-z)^2 + \frac{z}{2l\gamma^3} (2l-z) \\ &\quad - \frac{z}{l\gamma^3} \frac{l-z}{z} E_1 - \frac{z^3}{6l} (2l-z) \quad \dots \dots \dots (28) \end{aligned}$$

Equation for Deflection under Load.—When $x=0$ the deflection under the load y is—

$$I E y = K_1 (1-K_2) \left(B_1 + \frac{E_1}{\gamma^3} \right) P \text{ (equation 26)}$$

$$\text{calling } \frac{I E y}{P K_1 (1-K_2)} = \delta$$

$$\begin{aligned} \delta &= B_1 + \frac{E_1}{\gamma^3} \\ &= \frac{z}{l} \frac{E_1}{\gamma^3} - \frac{z^3}{l(2l-z)} \frac{E_2}{\gamma^3} + \frac{z}{\gamma^3} - \frac{z^3}{3} (2l-z). \end{aligned}$$

This gives a negative deflection; changing the sign throughout,

$$\delta = \frac{z^3}{3} (2l-z) + \frac{z}{\gamma^3} + \frac{z}{l} \frac{E_1}{\gamma^3} - \frac{z^3}{l(2l-z)} \frac{E_2}{\gamma^3}$$

$$\text{where } E_1 = \frac{1-e^{-\gamma z}}{1+e^{-\gamma z}} \text{ and } E_2 = \frac{1-e^{-\gamma(2l-z)}}{1+e^{-\gamma(2l-z)}} \quad \dots \dots \dots (29)$$

It is evident that E_2 is very nearly equal to unity if z is not greater than l . It will therefore be arranged always to make z not greater than l and to put $E_2 = 1$.

$$\delta = \frac{z^3}{3} (2l-z) + \frac{z}{l\gamma^3} \left(E_1 - \frac{z}{2l-z} \right) + \frac{z}{\gamma^3} \quad \dots \dots \dots (30)$$

This equation gives the value of δ (which is a quantity proportional to the deflection under the load) for an assumed "flexible" web-flange connection. The first quantity $\frac{z^2}{3}(2l-z)$ is the value of δ for the ordinary assumption of a "rigid" web-flange connection. The other portions of the expression involve γ and indicate the variation from the "rigid" deflection for any value of γ . The factor $\left(E_1 - \frac{z}{2l-z}\right)$ will always be less than unity; thus

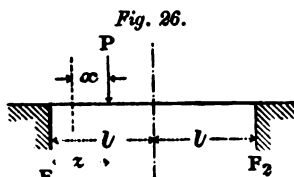
Value of z	Value of E_1	Value of $\frac{z}{2l-z}$	Value of $E_1 - \frac{z}{2l-z}$
0	0	0	0
l	1 (nearly)	1	0 (nearly);

consequently it appears probable that an approximate value of δ is—

$$\delta = z \left(\frac{z}{3}(2l-z) + \frac{1}{\gamma^2} \right) \dots \dots \dots (31)$$

It will be advisable to check the result of δ when $\gamma = 0$ by actual analysis of the case of a "rigid" flange-web connection.

Equation for Girder-Deflection due to Bending, with the Hypothesis of a "Rigid" Web-Flange Connection.—In order eventually to arrive at an expression for $\frac{IEy}{PK_1l - K_2}$ only the moment of inertia of the flange-area will be considered, so that "I" will mean the same as in the last section. To do



this the bending-moment must be reduced in the ratio $\frac{P}{b} \left(i.e. \frac{K_1}{P} \right)$.

$$M_1 = \frac{2l-z}{2l} P(z-x) \quad M_2 = \frac{z}{2l} P(2l-z-x)$$

$$F_1 = \frac{2l-z}{2l} P \quad F_2 = \frac{z}{2l} P.$$

Allowing for the reduced value of I, as stated above,

$$IE \frac{d^3 y_1}{dx^3} = \frac{P}{b} P \frac{2l-z}{2l} (z-x)$$

$$IE \frac{d^3 y_2}{dx^3} = \frac{P}{b} P \frac{z}{2l} (2l-z-x)$$

$$IE \frac{d^2 y_1}{dx^2} = \frac{P}{b} P \frac{2l-z}{2l} \left(zx - \frac{x^2}{2} + A_1 \right) = K_1 (1-K_2) \left(zx - \frac{x^2}{2} + A_1 \right) P$$

$$IE \frac{d^2 y_2}{dx^2} = \frac{P}{b} P \frac{z}{2l} \left(2lx - zx - \frac{x^2}{2} + A_2 \right) = K_1 K_2 \left(2lx - zx - \frac{x^2}{2} + A_2 \right) P$$

$$IE y_1 = K_1 (1-K_2) \left(\frac{zx^2}{2} - \frac{x^3}{6} + A_1 x + B_1 \right) P$$

$$IE y_2 = K_1 K_2 \left(lx^2 - \frac{zx^2}{2} - \frac{x^3}{6} + A_2 x + B_2 \right) P$$

Conditions

$$\left|_z y_1 = 0; \frac{z^3}{3} + A_1 z + B_1 = 0\right.$$

$$\left|_{2l-z} y_2 = 0; \frac{(2l-z)^3}{3} + (2l-z) A_2 + B_2 = 0\right.$$

$$\left|_0 y_1 = \right|_0 y_2; (1 - K_2) B_1 = K_2 B_2$$

$$\left|_0 \frac{d y_1}{d x} = \right|_0 \frac{d y_2}{d x}; (1 - K_2) A_1 = K_2 B_2$$

Eliminating A_1 ; $B_1 = \frac{z^3}{3}(2l-z)$. The deflection under load is given by

$$\left|_0 y_2.$$

Therefore $\delta = \frac{I E y}{K_1 (1 - K_2) P} = B_1 = \frac{z^3}{3}(2l-z)$

which agrees with the value of δ (equation 30) when $\gamma = 0$.

(Paper No. 3658.)

"Estimation of the Unbalanced Forces in Multi-cylinder One-crank Engines."

By ARCHIBALD SHARP, B.Sc., Assoc. M. Inst. C.E.

THE V-type of two-cylinder one-crank engine is being extensively employed for motor-bicycles and "tri-cars." Neither the weight nor the cost of production of this engine is as great as twice that of a one-cylinder engine of the same bore and stroke, and there appears to be no good reason why multi-cylinder one-crank engines should not be more widely adopted for motor-cars. Three-cylinder engines of this type have been used by at least one firm, and hydraulic engines having one crank and three or four cylinders with their axes all in the same plane at right-angles to the crank-shaft have long been in use. In a four-stroke cycle internal-combustion engine the maximum stresses on the crank-shaft with three, perhaps even five, cylinders at equal angles round the crank-case are no greater than with one cylinder of the same bore and stroke. For uniformity of turning-effort the impulses from the various cylinders should take place at equal intervals of time, and in a one-crank engine working on the four-stroke cycle with cylinders at equal angles round the crank-case this is possible only with an odd number of cylinders. The Author is of opinion that this type of engine can be made lighter than any other in proportion to its power; it may therefore become more prominent in its application to aerial navigation. In the following Paper the Author investigates the unbalanced forces in engines of this type.

Methods of Investigation.—The internal forces in the engine due to the mutual pressures between the several parts constitute a system in equilibrium, and have no direct bearing on the problem of balancing, except in so far as they produce acceleration of the moving parts. If at any instant there is a resultant torque causing angular acceleration of the shaft, there will be an equal and opposite torque tending to cause acceleration of the engine-frame and the parts to which it is fastened. Exact expressions for the acceleration of the piston and of the connecting-rod at any instant, or Klein's exact graphical

constructions, may be taken as the basis of the investigation; but since in many of the actual types of engines in use the primary unbalanced force due to one cylinder may be neutralized by that due to another cylinder, it is more convenient to take the expression for the acceleration in terms of the cosines of θ and even multiples of θ , the angle through which the crank has revolved from its initial position.

The motion of the connecting-rod is resolved into a linear motion of its mass-centre and an angular swing about an axis through its mass-centre. The linear motion of the mass-centre of the connecting-rod, and the forces required to produce it, are the same as for two equivalent masses at the crank-pin and crosshead-pin respectively, having the same total mass, and the same mass-centre as the connecting-rod. The equivalent mass at the crank-pin can be balanced perfectly by a counter-balance mass fastened to the crank, and therefore requires no further discussion; the equivalent mass at the crosshead-pin may be added to that of the piston, giving the total reciprocating mass. To produce the angular acceleration of the connecting-rod a transverse couple is required. The angular acceleration of the connecting-rod is expressed in terms of the sines of θ and odd multiples of θ . In some engines the primary transverse couples of the various connecting-rods may neutralize each other, leaving a resultant couple of higher order.

It will be assumed throughout the investigation that the angular speed of the crank is uniform. The influence of variation of the angular speed of the crank (due to variation of the driving torque) on the acceleration of the reciprocating masses is discussed in a Paper¹ by Mr. J. H. MacAlpine, published in *Engineering* in October, 1897, in which are also given the exact series for the acceleration of the crosshead and for the angular acceleration of the connecting-rod; these will be quoted later.

GENERAL ANALYTICAL INVESTIGATION.

Accelerating-forces on Pistons :—

Let O (*Fig. 1*) be the centre of the crank-shaft;

O C₁, O C₂, etc., the axes of the cylinders;

O X and O Y, the axes of reference, at right-angles to each other;

n , the number of cylinders;

¹ "Analysis of the Inertia Forces of the Moving Parts of an Engine." *Engineering*, vol. lxiv, pp. 511 and 543, October 22nd and 29th, 1897.

β_1, β_2 , etc., the angles C_1OX, C_2OX , which the axes of the cylinders make with the axis of reference OX ;

m_1, m_2 , etc., the corresponding reciprocating masses;

r , the length of the crank;

l , the length of the connecting-rod;

$q = \frac{r}{l}$, the maximum obliquity of the connecting-rod;

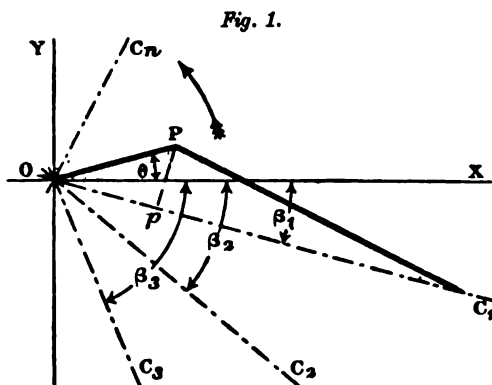


Fig. 1.

θ , the angle through which the crank has turned from OX at any instant;

ω , the angular speed of the crank = rate of change of θ ;

a_1, a_2 , etc., the accelerations of the reciprocating masses at the same instant;

f_1, f_2 , etc., the corresponding accelerating-forces;

a_{x1}, a_{x2} , etc., the component accelerations along OX ;

a_{y1}, a_{y2} , etc., the component accelerations along OY ;

f_{x1}, f_{x2} , etc., and f_{y1}, f_{y2} , etc., the corresponding component accelerating-forces;

and F_x and F_y the total component accelerating-forces along OX and OY respectively due to the n cylinders.

Then, as shown in text-books (*e.g.*, Professor Dalby's "Balancing of Engines")—

$$-\frac{f_1}{\omega^2 r} = m_1 \{ \cos(\theta + \beta_1) + B_2 \cos 2(\theta + \beta_1) + B_4 \cos 4(\theta + \beta_1) + \dots \} \quad (1)$$

B_2, B_4 , etc., having the following values, as shown in the Paper by Mr. MacAlpine, already referred to:—

$$B_2 = q + \frac{1}{4} q^3 + \frac{15}{128} q^5 + \dots$$

$$B_4 = -\frac{1}{4} q^3 - \frac{3}{16} q^5 - \dots$$

$$B_6 = \frac{9}{128} q^5 + \dots$$

For approximations it will be sufficient to use only the first term of these expressions.

Multiplying both sides of equation (1) by $2 \cos \beta_1$,

$$-\frac{2f_{x1}}{\omega^2 r} = 2 m_1 \cos \beta_1 \{ \cos (\theta + \beta_1) + B_2 \cos 2 (\theta + \beta_1) + B_4 \cos 4 (\theta + \beta_1) + \dots \} \quad (2x)$$

$$\begin{aligned} \text{or } -\frac{2f_{x1}}{\omega^2 r} &= m_1 \cos \theta + m_1 \cos (\theta + 2 \beta_1) \\ &+ B_2 [m_1 \cos (2 \theta + \beta_1) + m_1 \cos (2 \theta + 3 \beta_1)] \\ &+ B_4 [m_1 \cos (4 \theta + 3 \beta_1) + m_1 \cos (4 \theta + 5 \beta_1)] + \\ &+ B_k [m_1 \cos (k \theta + k - 1 \beta_1) + m_1 \cos (k \theta + k + 1 \beta_1)] + \dots \quad (3) \end{aligned}$$

with similar expressions for f_{x2} , etc.

For n cylinders

$$\begin{aligned} -\frac{2 F_x}{\omega^2 r} &= \Sigma m \cos \theta + \Sigma m \cos (\theta + 2 \beta) \\ &+ B_2 \{ \Sigma m \cos (2 \theta + \beta) + \Sigma m \cos (2 \theta + 3 \beta) \} \\ &+ B_4 \{ \Sigma m \cos (4 \theta + 3 \beta) + \Sigma m \cos (4 \theta + 5 \beta) \} + \\ &+ B_k \{ \Sigma m \cos (k \theta + k - 1 \beta) + \Sigma m \cos (k \theta + k + 1 \beta) \} + \dots \quad (4x) \end{aligned}$$

Similarly, multiplying both sides of equation (1) by $2 \sin \beta_1$,

$$\begin{aligned} -\frac{2f_{y1}}{\omega^2 r} &= 2 m_1 \sin \beta_1 \{ \cos (\theta + \beta_1) + B_2 \cos 2 (\theta + \beta_1) \\ &+ B_4 \cos 4 (\theta + \beta_1) + \dots \} \quad (2y) \end{aligned}$$

and for n cylinders,

$$\begin{aligned} -\frac{2 F_y}{\omega^2 r} &= \Sigma m \sin \theta - \Sigma m \sin (\theta + 2 \beta) \\ &+ B_2 \{ \Sigma m \sin (2 \theta + \beta) - \Sigma m \sin (2 \theta + 3 \beta) \} \\ &+ B_4 \{ \Sigma m \sin (4 \theta + 3 \beta) - \Sigma m \sin (4 \theta + 5 \beta) \} + \\ &+ B_k \{ \Sigma m \sin (k \theta + k - 1 \beta) - \Sigma m \sin (k \theta + k + 1 \beta) \} + \dots \quad (4y) \end{aligned}$$

Σm , $\Sigma m \cos (\theta + 2 \beta)$, and similar expressions denoting in each case the sum of such terms obtained by placing the suffixes 1, 2, . . . n , to the symbols m and β . Comparing equations (4x) and (4y) with equation (1), it is seen that the total component accelerating-force along each axis of reference is made up of a primary accelerating-force and the even harmonics, as for the case of a single-cylinder engine in equations (2x) and (2y); but in this case the primary accelerating-force, as well as each harmonic, is made up of two terms.

Primary Forward Unbalanced Force.—The first terms of the primary component accelerating-forces on the right-hand side of equations (4x) and (4y) are respectively

$$\Sigma m \cos \theta, \text{ and } \Sigma m \sin \theta. \quad \dots \dots \dots (5)$$

These are the projections along $O X$ and $O Y$ respectively (*Fig. 2*) of a vector of length Σm set off along the crank OP , and revolving with it. Therefore, these parts of the primary component accelerating-forces are the same as those due to a mass M_1 fixed to the crank-pin, such that

$$2 M_1 = \Sigma m, \text{ or } M_1 = \frac{1}{2} \Sigma m (6)$$

M_1 may be called the primary forward unbalanced mass-vector. It can be balanced by an equal mass-vector opposite to the crank and revolving with it. Thus the primary forward unbalanced force can always be eliminated by having a balance-mass, equal to one-half that of all the reciprocating masses, fixed opposite the crank-pin at the same radius as the crank-pin.

Primary Reverse Unbalanced Force.—The second terms of the primary component accelerating-forces in equations (4x) and (4y) are respectively

$$\Sigma m \cos (\theta + 2 \beta), \text{ and } - \Sigma m \sin (\theta + 2 \beta) . . . (7)$$

In *Fig. 3* let the vectors OA_0, A_0B_0, B_0C_0 , etc., having lengths m_1, m_2, m_3 , etc., make angles $2\beta_1, 2\beta_2, 2\beta_3$, etc., with $O X$ in the direction opposite to the rotation of the crank, and let $O Q_0$ be the resultant of the n vectors.

When the crank is in the initial position OP_0 , coincident with $O X$, let an imaginary vector revolving with the same speed, but in the opposite sense, be in the position $O Q_0$. When the crank has rotated through the angle θ into the position OP , the imaginary vector will have rotated into the position OQ , and the vector-polygon into the position $O A B Q$, not shown in the Figure. The projections of $O A$ along $O X$ and $O Y$ are respectively $m_1 \cos (\theta + 2\beta_1)$ and $- m_1 \sin (\theta + 2\beta_1)$; and similar expressions obtain for the projections of $A B, B C$, etc. It is then evident that the projections

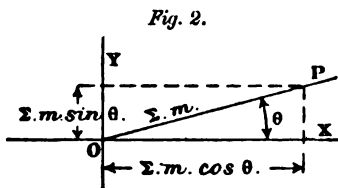


Fig. 2.

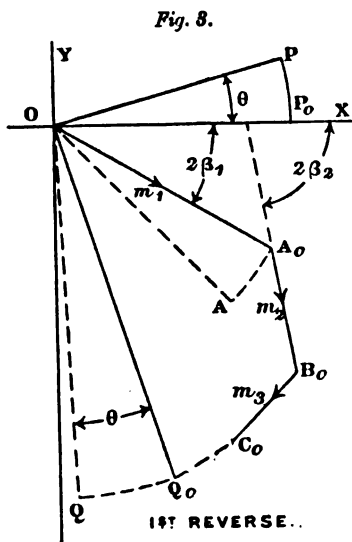


Fig. 3.

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of OQ along OX and OY respectively are represented by the expressions

$$\Sigma m \cos (\theta + 2 \beta), \text{ and } - \Sigma m \sin (\theta + 2 \beta).$$

Thus the second terms in the primary component accelerating-forces are the same as those due to a mass-vector M_1^1 revolving with the same speed as the crank, but in the opposite sense. M_1^1 may be called the primary reverse unbalanced mass-vector.

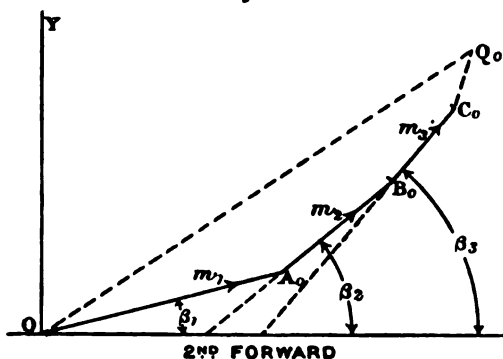
Evidently $2 M_1^1 = \overline{OQ_0}$ (8)

OQ_0 (*Fig. 3*) shows the initial direction of the primary reverse unbalanced mass-vector, corresponding to the initial direction OP_0 of the crank.

It is in general impracticable to arrange in an engine a counter-balance mass revolving in the opposite direction to that

of the crank. The primary reverse unbalanced force acting in any given direction may be partially or completely balanced by a counter-balance mass revolving with the crank, at the expense, however, of increasing the want of balance in the direction at right-angles.

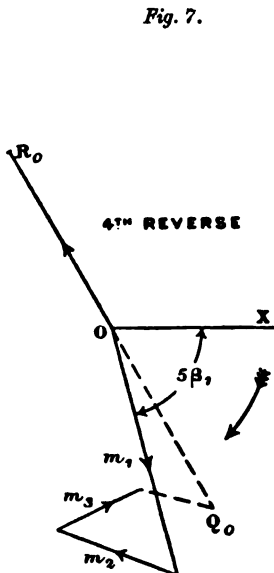
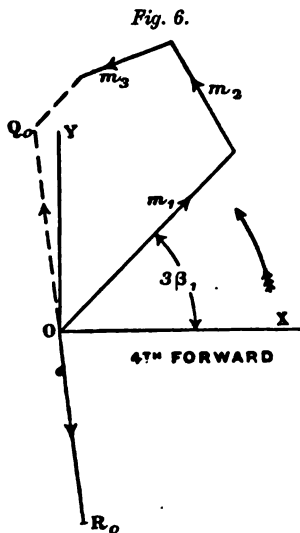
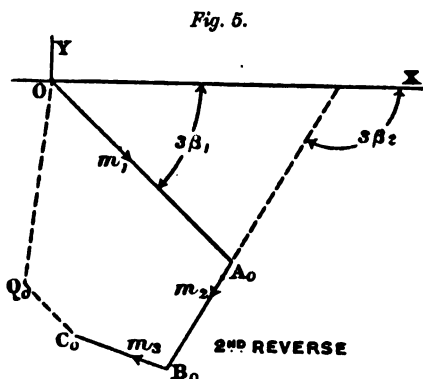
Fig. 4.



Secondary Unbalanced Force.—It can be shown, in the same manner, that the terms in the expressions (4x) and (4y) for Fx and Fy , which involve the angle 2θ , and which are multiplied by the coefficient B_2 , are the same as would be given by two revolving mass-vectors rotating at twice the angular speed of the crank, the rate of change of the angle 2θ being 2ω , i.e. twice the rate of change of θ ; they may be referred to as the secondary forward and reverse unbalanced mass-vectors. The initial position of the secondary forward mass-vector polygon is shown in *Fig. 4*, the sides OA_0 , A_0B_0 , etc., making the angles β_1 , β_2 , etc., with OX . The initial position of the secondary reverse mass-vector polygon is shown in *Fig. 5*, the sides OA_0 , A_0B_0 , etc., making the angles $-3\beta_1$, $-3\beta_2$, etc., with OX . Evidently, in *Fig. 4*, the projections of OQ_0 along OX and OY respectively are equal to $\Sigma m \cos$

($2\theta + \beta$) and $\Sigma m \sin (2\theta + \beta)$, when $\theta = 0$. Similarly, in *Fig. 5*, the projections of OQ_0 along OX and OY respectively are equal to $\Sigma m \cos (2\theta + 3\beta)$ and $-\Sigma m \sin (2\theta + 3\beta)$, when $\theta = 0$.

Unbalanced Forces of Higher Orders.—In the same manner, comparing the terms in equations (3) and (4) involving the angle $k\theta$, it is evident that the forward mass-vector polygon of the k th order is obtained by a construction analogous to that shown in *Fig. 4*, the mass-vectors m_1, m_2 , etc., being set off at the angles $(k-1)\beta_1, (k-1)\beta_2$, etc., with OX . Similarly, the reverse mass-vector polygon of the k th order is obtained by a construction analogous to that shown in *Fig. 5*, the mass-vectors being set off at the angles $-(k+1)\beta_1, -(k+1)\beta$,



etc., with OX . Hence, the two mass-vector polygons, the reverse of order k and the forward of order $(k+2)$, are equal and similar,

but lie symmetrically on opposite sides of the initial line OX , *Figs. 11-15*.

The forward and reverse mass-vector polygons of the fourth order are shown in *Figs. 6* and *7* respectively. As the coefficients B_4 , B_8 , etc., in equations (1), (4 x) and (4 y) are negative, and as it is desirable to draw all mass-vectors so that the corresponding forces of acceleration shall be directed towards the centre, in *Figs. 6* and *7*, Q_0O is produced to R_0 , making $OR_0 = Q_0O$. OR_0 may then be regarded as the initial position of the resultant mass-vector, which on being multiplied by $\omega^2 \frac{r}{2}$ gives the corresponding accelerating-force.

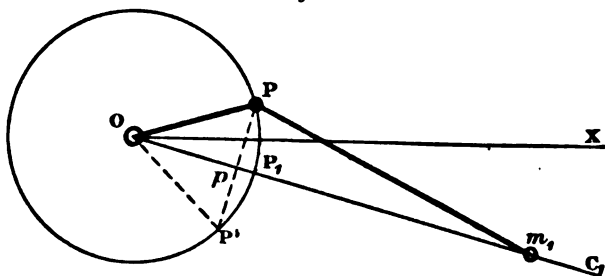
GEOMETRICAL INVESTIGATION.

Primary Balancing.—The foregoing results can be obtained by a graphical method.

The primary force of acceleration of the piston m_1 moving along the centre-line OC_1 is that due to a simple harmonic motion of the mass m_1 along OC_1 .

From the crank-pin P (*Fig. 8*) Pp is drawn perpendicular to OC_1 , and is produced to cut the crank-pin circle again at P' . So far as

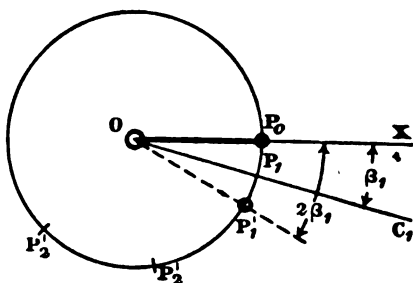
Fig. 8.



the primary force of acceleration is concerned, the reciprocating mass m_1 may be considered as concentrated at p . But two masses, each $\frac{1}{2} m_1$, at P and P' respectively, are equivalent to a mass m_1 at p . Hence the mass m_1 , reciprocating with simple harmonic motion along OC_1 , is equivalent to a mass $\frac{m_1}{2}$ fixed to the crank-pin P and a mass $\frac{m_1}{2}$ fixed to an imaginary crank-pin P' moving in the reverse direction, the two crank-pins P and P' coinciding at P_1 on the line of stroke OC_1 .

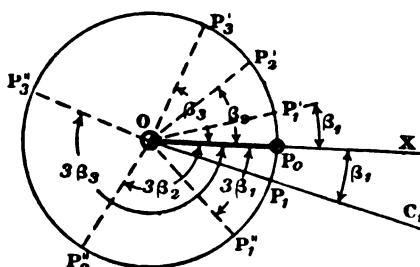
In *Fig. 9*, when the crank-pin is at P_0 , on the initial line of reference OX , the equivalent forward mass, $\frac{1}{2} m_1$, has rotated forwards through the angle β_1 , from the position P_1 on the line of stroke OC_1 , while the equivalent reverse mass has rotated backwards through the same angle β_1 into the position P'_1 . Thus, when the crank-pin is at P_0 , the equivalent reverse mass $\frac{m_1}{2}$ is at P'_1 , at an angle $2\beta_1$ from the initial line OX .

Fig. 9.



Similarly, for the masses m_2 , m_3 , etc., reciprocating along the lines OC_2 , OC_3 , etc. (*Fig. 1*), when the crank-pin is at P_0 (*Fig. 9*) the equivalent forward masses are each at P_0 , and the equivalent reverse masses $\frac{1}{2} m_2$, $\frac{1}{2} m_3$, etc., are at P'_2 , P'_3 , etc., respectively, at the angles $2\beta_2$, $2\beta_3$, etc., from the initial line OX . The resultant reverse mass-vector OQ_0 is therefore obtained by the construction shown in *Fig. 3*.

Fig. 10.



Secondary Balance.—From equation (1) the secondary acceleration a_1 along the line of stroke OC_1 is given by the expression

$$-\frac{a_1}{\omega^2 r} = B_2 \cos 2(\theta + \beta_1),$$

and the secondary accelerating-force by the expression

$$-\frac{f_1}{\omega^2 r} = B_2 m_1 \cos 2(\theta + \beta_1),$$

the maximum value of the latter being $B_2 m_1 \omega^2 r$. As already shown, these are the same as those due to two masses revolving in the forward and reverse directions at twice the speed of the crank, the radial accelerating force of each being $\frac{1}{2} B_2 m_1 \omega^2 r$, and the two masses coinciding at the line of stroke.

When the crank-pin is at P_0 it has revolved through the angle β_1 from P_1 (*Fig. 10*), and the equivalent forward secondary mass has

revolved through the angle $2\beta_1$, and is in the position P'_1 , the angle $P_0O P'_1$ being equal to β_1 . The resultant forward secondary mass-vector OQ_0 is therefore obtained by the construction shown in *Fig. 4*. The corresponding position for the equivalent reverse secondary mass is at P''_1 , the angle $XO P''_1$ being obviously $-3\beta_1$. The resultant reverse secondary mass-vector OQ_0 is therefore obtained by the construction shown in *Fig. 5*.

ACCELERATION COUPLES OF CONNECTING-RODS.

The transverse couple c_1 required to produce the angular acceleration of the connecting-rod of the cylinder with axis OC_1 (*Fig. 1*), or the equal opposite unbalanced transverse couple on the frame, can be expressed by a series of sines of odd multiples of $(\theta + \beta_1)$, thus¹

$$c_1 = \omega^2 I_1 \{ D_1 \sin(\theta + \beta_1) + D_3 \sin 3(\theta + \beta_1) + D_5 \sin 5(\theta + \beta_1) \dots \} \quad (9)$$

where I_1 is the moment of inertia of the connecting-rod about an axis through its mass-centre parallel to the crank-shaft, and where D_1, D_3, D_5 , etc., have the following values¹:—

$$D_1 = q + \frac{1}{8} q^3 + \frac{3}{64} q^5 + \dots$$

$$D_3 = -\frac{3}{8} q^3 - \frac{27}{128} q^5 - \dots$$

$$D_5 = \frac{15}{128} q^5 + \dots$$

with expressions similar to (9) for the transverse acceleration couples of the other connecting-rods. In approximations, the first term only of these expressions need be used.

For the n connecting-rods, remembering that the axis of each couple is parallel to the crank-shaft and does not depend on the direction of the cylinder (*Fig. 1*), the resultant couple is obtained by algebraic addition. Therefore,

$$C = \omega^2 \{ D_1 \sum I \sin(\theta + \beta) + D_3 \sum I \sin 3(\theta + \beta) + \dots \} \quad (10)$$

the sign of summation $\sum$ denoting the sum of the terms obtained by placing the suffixes 1, 2, $\dots$ n successively to the symbols I and β .

The first term on the right-hand side of equation (10) is the primary unbalanced transverse couple. By reasoning similar to

¹ *Engineering*, 22 October, 1897.

that adopted in considering the primary and secondary unbalanced forces, $\Sigma I \sin (\theta + \beta)$ is evidently the projection on O Y of a resultant vector rotating at the same speed as the crank. When θ is zero, this resultant I-vector is got by a construction similar to that shown in *Fig. 4* for the secondary forward unbalanced force; I_1, I_2 , etc., being set off to scale instead of m_1, m_2 , etc., at the angles β_1, β_2 , etc., from the axis of reference O X.

$\Sigma I \sin 3 (\theta + \beta)$, involved in the unbalanced transverse couple of the third order, is the projection on O Y of a resultant vector rotating at three times the speed of the crank, the rate of change of the angle $(3 \theta + \beta)$ being 3ω , i.e. three times the rate of change of θ . When $\theta = 0$, this resultant I-vector is got by setting off the vectors I_1, I_2 , etc., at the angles $3 \beta_1, 3 \beta_2$, etc., with the axis of reference O X, a construction similar to that of *Fig. 6* for the forward unbalanced force of the fourth order.

Similarly, for the couples of any higher order, the I-vector polygon of order k is drawn by setting off the vectors I_1, I_2 , etc., at the angles $k \beta_1, k \beta_2$, etc., with the axis of reference O X.

As the coefficients D_3, D_7 , etc., in equations (9) and (10) are negative, the corresponding resultant I-vectors O Q may be set off in the opposite direction, for reasons similar to those previously discussed in considering unbalanced forces of the higher orders.

EXAMPLES.

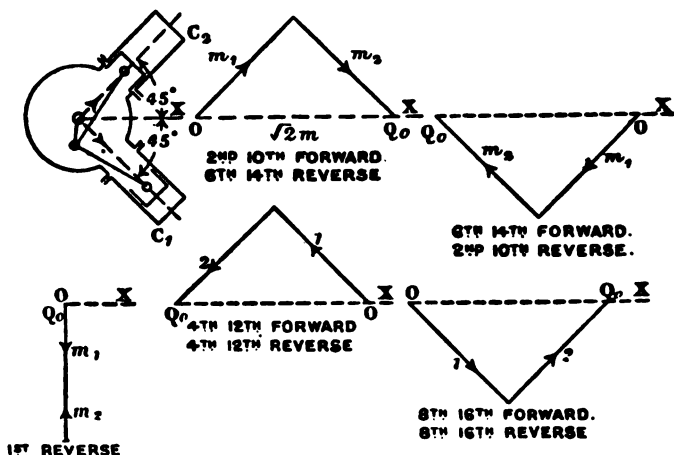
The general methods discussed in the foregoing can be readily applied to any particular case. The following examples are, with one exception, cases in which the primary reverse unbalanced force is zero; i.e., O and Q (*Fig. 3*) coincide, and therefore the primary balance can be made perfect by a counter-balance mass fixed to the crank-shaft. The reciprocating mass for each cylinder is denoted by m , and the moment of inertia of each connecting-rod about an axis through its mass-centre parallel to the crank-shaft by I. Denoting $\frac{\omega^2 r}{g}$ by A, and $\frac{\omega^2}{g}$ by T the values of the unbalanced forces and transverse couples are then expressed in gravitation units. In these symmetrical engines the various mass-vector polygons repeat themselves, as is shown by *Figs. 11-15*.

Two Cylinders at 90°.—In *Figs. 11* are shown the position of the cylinders and the various mass-vector polygons, the axis of reference, O X, being taken symmetrically in relation to the two cylinders. The initial positions of the forward and reverse resultant mass-vectors of the 2nd, 6th, . . . orders, when the crank is on O X,

are respectively at angles of 0° and 180° with OX ; that is, their epoch-angles are 0° and 180° respectively, the epoch-angle being the angle which the resultant mass-vector OQ_0 makes with OX , when the crank is coincident with OX . Taking as an approximate value for B_2 the first term in the series, i.e., $B_2 = q$, the secondary forward and reverse unbalanced forces are each $\frac{1}{\sqrt{2}} A m q$. The two equal forces of any order rotating in opposite directions have a resultant always at right-angles to OX . When $\theta = 45^\circ$, this resultant is $\sqrt{2} A m q$.

In this engine, the resultant mass-vectors of all orders except the first are each equal to $\sqrt{2} m$; OQ_0 for the 4th, 8th, ... orders,

Figs. 11.



forward and reverse, coincide, and the corresponding forces have resultant of varying magnitude always in the direction OX .

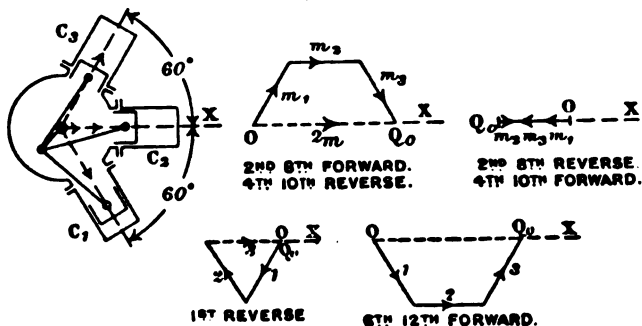
The primary I-vector polygon is similar to the second forward unbalanced force-polygon, i.e., the resultant $OQ_0 = \sqrt{2} I$. The maximum primary transverse couple is $\sqrt{2} T I q$. The epoch-angle is 0° .

Three Cylinders at 60° .—The various vector-polygons are shown in Figs. 12. The resultant secondary forward and reverse mass-vectors are $2m$ and m respectively; their epoch-angles are 0° and 180° respectively. The secondary forward and reverse unbalanced forces are respectively $A m q$ and $\frac{1}{2} A m q$. These two unequal forces, rotating in opposite directions, have a resultant of minimum value

$\frac{1}{2} A m q$ along $O X$ and of maximum value $\frac{3}{2} A m q$ at right-angles to $O X$, the resultant force-diagram being an ellipse.¹

The maximum primary transverse couple is $2 T I q$. The epoch angle is 0° .

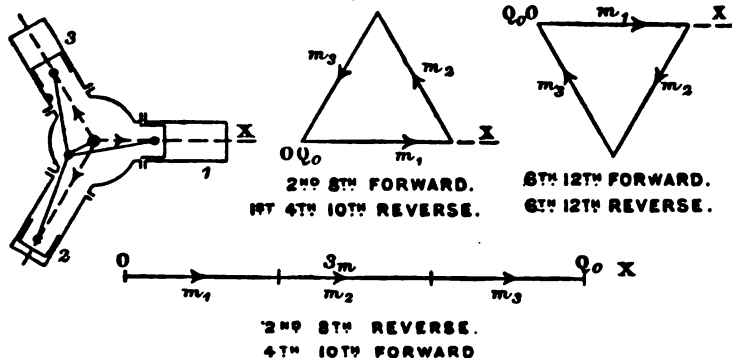
Figs. 12.



Three Cylinders at 120° .—(Figs. 13.) The primary reverse and the secondary forward unbalanced force are each zero; the secondary reverse unbalanced force is $\frac{3}{2} A m q$; the epoch-angle is 0° .

The fourth forward mass-vector polygon is the same as the second reverse polygon. The fourth reverse resultant vector is zero. The

Figs. 13.



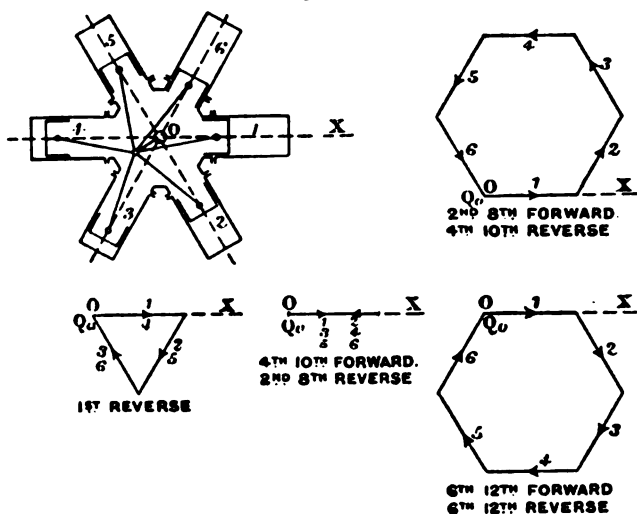
fourth forward unbalanced force is $\frac{3}{2} \times \frac{1}{4} A m q^2 = \dots \frac{3}{8} A m q^2$. The epoch-angle is 180° .

The resultant primary I-vector is zero, and that of the third order is $3 I$. The maximum couple, which is of the third order, is $\frac{9}{8} T I q^2$. The epoch-angle is 180° .

¹ See W. E. Dalby, "The Balancing of Engines." London, 1902.

Even Number of Cylinders at Equal Angles.—Let $n = 2k$, where k is any integer; the angle between two adjacent cylinders is then $\frac{\pi}{k}$. The exterior angles of the various mass-vector polygons, with the exception of the first reverse polygon (Fig. 3), are $\frac{\pi}{k}, \frac{3\pi}{k}, \frac{5\pi}{k}, \frac{7\pi}{k}$, etc., none of which are multiples of 2π . From the symmetry of the arrangement of the n cylinders, the derived mass-vector polygons are all symmetrical, and therefore must be closed unless the exterior angle between two adjacent sides is 2π or a multiple of 2π .

Figs. 14.



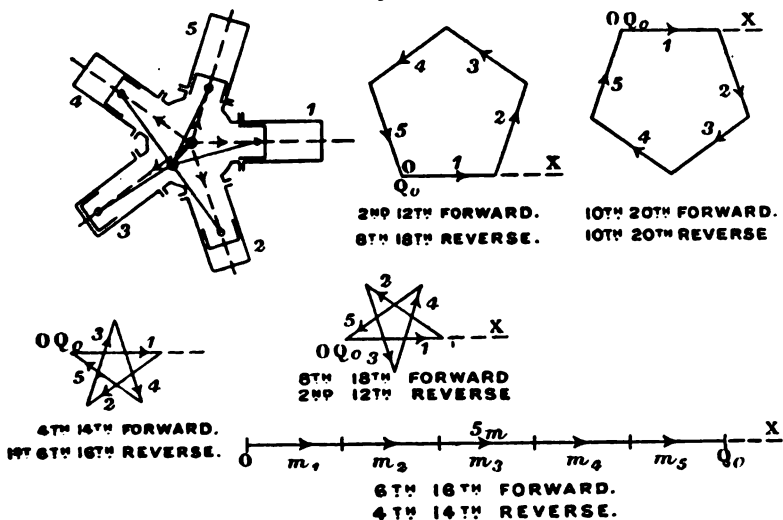
The primary reverse mass-vector polygon (Fig. 3) has its exterior angle $\frac{2\pi}{k}$. If $k = 1$, i.e., $n = 2$, corresponding to two opposed cylinders (at 180°), the exterior angle is 2π , and the resultant mass-vector is $2m$. That is, the primary balance is just the same as in a single-cylinder engine having the same total reciprocating mass. The exterior angles of the other mass-vector polygons are $\pi, 3\pi, 5\pi, \dots$, and the resultant mass-vector OQ_0 in each case is zero, i.e., no unbalanced forces of higher order than the primary are present.

For any other value of k the exterior angle cannot be a multiple of 2π . Therefore, for an even number of cylinders greater than two, at equal angles, there are no unbalanced forces. The I-vector polygons have the exterior angles $\frac{\pi}{k}, \frac{3\pi}{k}, \frac{5\pi}{k}$, and are therefore all

closed ; i.e., the resultant I-vectors are all zero. Hence, for an even number of cylinders greater than two, the balance is mathematically perfect. The foregoing reasoning is illustrated by *Figs. 14*, which show an engine with six cylinders at 60° , and its derived mass-vector polygons.

It may be of some academic interest to note that one-crank engines with four or six cylinders at equal angles, and with suitable counterbalance masses on the crank-shaft, are mathematically in

Figs. 15.



better balance than the usual type of six-cylinder six-crank engine. In the latter there is an unbalanced transverse couple of the third order, of maximum value $\frac{9}{4} T I q^3$.

Odd Number of Cylinders at Equal Angles.—Three cylinders at 120° , already discussed, is a particular example of the more general case. If n is the number of cylinders, the angle between two adjacent cylinders is $\frac{2\pi}{n}$. Taking $O X$, the axis of reference, coincident with the axis of one cylinder, the forward and reverse mass-vector polygons of the r th order have the angle between a pair of adjacent vectors $\frac{(r-1)2\pi}{n}$ and $\frac{(r+1)2\pi}{n}$ respectively. Thus, when $(r-1) = k n$, the angle of the forward mass-vector polygon is $2k\pi$, where k is any integer, i.e., the n sides are all in the same

direction, and $OQ_0 = nm$. Similarly, when $(r+1) = kn$ the angle of the reverse vector polygon is $2k\pi$, and $OQ_0 = nm$. For all other values of r the resultant mass-vector OQ is zero, as is evident from the symmetry of the mass-vector polygons. Thus all the unbalanced forces of all orders are zero, except the reverse forces of the orders $(kn-1)$, and the forward forces of the orders $(kn+1)$. Also, since the expressions $(kn-1)$ and $(kn+1)$ are even, and n is odd, k must be an odd integer.

The I-vector polygons are all closed, except those of the orders n or integral multiples of n . In each of these the resultant I-vector is nI .

Five Cylinders at 72° .—The mass-vector polygons for five cylinders are shown in *Figs. 15*. The reverse unbalanced force of the fourth order is $\frac{5m}{2} A \frac{q^3}{4} = \frac{5}{8} Amq^3$. The epoch-angle is 180° .

The maximum transverse couple of the fifth order is

$$5IT \times \frac{15}{128} q^5 = \frac{75}{128} TI q^5.$$

The epoch-angle is 0° .

Numerical Results.—Let the stroke be 5 inches and the connecting-rod length $12\frac{1}{2}$ inches; then $r = 2.5$ inches = 0.209 foot, and $q = \frac{2.5}{12.5} = 0.2$. Let the weight of each piston, with its rings, be 8 lbs., and the weight of the connecting-rod 8 lbs., equivalent to 3 lbs. at the gudgeon-pin and 5 lbs. at the crank-pin. Then $m = 8 + 3 = 11$ lbs. Let $I = \frac{8 \text{ lbs.} \times (15 \text{ inches})^2}{12} = 150$ lb.-inch units = 1.04 lb.-foot units. Let ω be 1,000 revolutions per minute = 104.7 radians per second.

$$\text{Then } A = \frac{\omega^2 r}{g} = \frac{104.7^2 \times 0.209}{32.2} = 71.1$$

$$T = \frac{\omega^2}{g} = \frac{104.7^2}{32.2} = 340.3 \text{ feet}^{-1}$$

$$Am = 71.1 \times 11 = 782.1 \text{ lbs. weight}$$

$$TI = 340.3 \times 1.04 = 353.9 \text{ lb.-foot units.}$$

The results for the foregoing examples are tabulated in the Appendix; in each case the epoch-angle is stated in the first line, the expression for the unbalanced force or couple in the second line, and the numerical values for the data assumed in the examples in the third line.

The Paper is accompanied by four sheets of drawings, from which the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

	Position of Reference Line O X.	Unbalanced Forces.						Transverse Couples.		
		Primary.	Second Order.		Fourth Order.		Primary.	Third Order.	Fifth Order.	
			Forward.	Reverse.	Forward.	Reverse.				
Two cylinders at 90° . .	$\left\{ \begin{array}{l} \text{Bisecting} \\ \text{angle } 90^\circ \\ \text{between} \\ \text{cylinders} \end{array} \right\}$	0	$\left\{ \begin{array}{l} 0^\circ \\ \frac{1}{\sqrt{2}} A m q \\ 110 \text{ lbs.} \end{array} \right\}$	$\left\{ \begin{array}{l} 180^\circ \\ \frac{1}{\sqrt{2}} A m q \\ 110 \text{ lbs.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{1}{4\sqrt{2}} A m q^3 \\ 1.1 \text{ lb.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{1}{4\sqrt{2}} A m q^3 \\ 1.1 \text{ lb.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \sqrt{2} T I q \\ 99.7 \text{ lb.-ft.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{3\sqrt{2}}{8} T I q^3 \\ 2.1 \text{ lb.-ft.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{15\sqrt{2}}{128} T I q^5 \\ 0.002 \text{ lb.-ft.} \end{array} \right\}$	
Two cylinders at 180° . .	$\left\{ \begin{array}{l} \text{Axis of} \\ \text{cylinder} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ A m \\ 782 \text{ lbs.} \end{array} \right\}$	0	0	0	0	0	0	0	
Three cylinders at 60° . .	$\left\{ \begin{array}{l} \text{Axis of} \\ \text{middle} \\ \text{cylinder} \end{array} \right\}$	0	$\left\{ \begin{array}{l} 0^\circ \\ A m q \\ 156 \text{ lbs.} \end{array} \right\}$	$\left\{ \begin{array}{l} 180^\circ \\ \frac{1}{3} A m q \\ 78 \text{ lbs.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{1}{3} A m q^3 \\ 0.78 \text{ lb.} \end{array} \right\}$	$\left\{ \begin{array}{l} 180^\circ \\ \frac{1}{3} A m q^3 \\ 1.56 \text{ lb.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ 2 T I q \\ 141 \text{ lb.-ft.} \end{array} \right\}$	$\left\{ \begin{array}{l} 0^\circ \\ \frac{8}{3} T I q^3 \\ 1.1 \text{ lb.-ft.} \end{array} \right\}$	$\left\{ \begin{array}{l} 180^\circ \\ \frac{16}{3} T I q^5 \\ 0.003 \text{ lb.-ft.} \end{array} \right\}$	
Three cylinders at 120° . .	$\left\{ \begin{array}{l} \text{Axis of a} \\ \text{cylinder} \end{array} \right\}$	0	0	$\left\{ \begin{array}{l} 0^\circ \\ \frac{1}{3} A m q \\ 234 \text{ lb.} \end{array} \right\}$	$\left\{ \begin{array}{l} 180^\circ \\ \frac{1}{8} A m q^3 \\ 2.3 \text{ lbs.} \end{array} \right\}$	0	0	$\left\{ \begin{array}{l} 180^\circ \\ \frac{8}{3} T I q^3 \\ 3.2 \text{ lb.-ft.} \end{array} \right\}$	0	
Five cylinders at 72° . .	$\left\{ \begin{array}{l} \text{Axis of a} \\ \text{cylinder} \end{array} \right\}$	0	0	0	0	$\left\{ \begin{array}{l} 180^\circ \\ \frac{8}{3} A m q^3 \\ 3.9 \text{ lbs.} \end{array} \right\}$	0	0	$\left\{ \begin{array}{l} 0^\circ \\ \frac{15}{128} T I q^5 \\ 0.007 \text{ lb.-ft.} \end{array} \right\}$	
Even number of cylinders, greater than two, at equal angles . .	..	0	0	0	0	0	0	0	0	

(Paper No. 3631.)

"Stamp-Mill Reduction-Plant of the New Kleinfontein Company, Limited, Witwatersrand, Transvaal."

By EDWARD JOHN WAY, Assoc. M. Inst. C.E.

On the 26th December, 1900, a raid was made by a party of Boers against the property of the New Kleinfontein Company, and owing to inadequate military protection nearly the whole of the surface-plant, consisting of a mill of 160 stamps, with boiler-house and engine-room, compressor-plant, crusher-station and sorting-floors, and all the trestle-work in connection with these departments, was destroyed by fire.

Early in 1901, the Author received instructions to prepare plans and estimates for an entirely new plant. Various schemes had to be considered, owing to the financial position of the Company, and it was finally decided to take in an additional 140 claims on dip-ground and to erect upon an approved site a complete 200-stamp mill installation. At the time when the plans were being prepared, the outlook with regard to unskilled labour was extremely doubtful, and throughout the design of the surface equipment the saving of hand-labour was the predominating note; wherever by approved mechanical means hand-labour could be dispensed with, it was done. A branch railway with various sidings, having a total length of $7\frac{1}{2}$ miles, was laid out and completed to serve the New Kleinfontein mine and the other mines in the Kleinfontein Group, replacing the old method of bullock- and mule-transport from the nearest railway stations, which had been in vogue previously to the war. This was necessary, as the new scheme of equipment entailed the handling of machinery, parts of which, weighing as much as 20 tons in single castings, could not have been handled by the old method of transport. It is estimated that the New Kleinfontein Company's share of the cost of this railway was more than covered by the saving effected by the new method of transport before any of the machinery was even erected, to say nothing of the saving of the increased capital expenditure

which would have been incurred had it been necessary to design parts of engines, etc., to meet the conditions of transport.

In this Paper the Author presents a detailed description of the new plant, and in the Appendixes are given some figures showing the cost of various items in the work, and a short summary of the performance of the various constituent parts of the plant. The total amount of money spent by the New Kleinfontein Company from the time the works were shut down on account of the war to the time of the completion of its new equipment was £801,169, including war losses, and in the spending of so large a sum upon one mining venture many interesting problems have occurred and many new departures have been brought into practice, which have led the Author to believe that an account of the work would be of interest to engineers.

CENTRAL POWER-PLANT.

The central power-plant (Figs. 1, Plate 4) comprises :—The main coal-bunkers, with conveyor, coal-crusher and elevator; the boiler-house, containing the automatic coal-handling plant, boilers and superheaters, ash-handling plant, economizer and induced-draught plant; the engine-room, containing the mill-engines, electric generators, air-compressors, winding-engines, condensing-plant, and Cornish pumping-plant, and the circulating-water plant.

Main Coal-Bunkers.—The main coal-bunkers have been constructed below ground-level, and a siding from the branch-line to the mine has been carried over them, enabling the coal to be dumped directly from the coal-trucks into the bunkers. The bunkers are 110 feet in length, have a storage-capacity of 250 tons, and are fitted with hoppers and adjustable shoots for feeding the coal as required on to the coal-conveyor, M. This conveying-belt is 30 inches in width, 102 feet $4\frac{1}{2}$ inches between pulley-centres, and running at a speed of 150 feet per minute is capable of delivering 20 tons of coal per hour to the coal-crusher. The coal passing over the head end of conveyor M, falls on to a shoot, which feeds it to a coal-crusher of the ordinary roll-type, where it is broken up into $\frac{1}{4}$ -inch cubes, and falling through to a second shoot is discharged directly into the boot of the coal-elevator. This elevator, of the open running-bucket type, lifts the crushed coal a vertical height of 49 feet to the upper floor of the elevator-house, a building 31 feet 2 inches by 16 feet 2 inches in outside measurements, carried on trestling at a height of 15 feet 2 inches above ground-level, where it is discharged on to a shoot which delivers it to con-

veyor N. A 50-HP. motor placed on the lower floor of this building drives a countershaft from which four belt-drives are taken, operating through intermediate gearing the coal-crusher, the head end of conveyor M, the head end of the coal-elevator, and the tail end of conveyor N.

Conveyor N carries the crushed coal delivered by the coal-elevator to the storage-bunkers in the boiler-house. Starting in the elevator-house 10 feet below the head of the coal-elevator, it is carried horizontally on trestling for a distance of 60 feet, to the boiler-house, and then through the boiler-house on staging supported by the tie-beams of the roof-trusses. Within the boiler-house the conveyor is fitted with an automatic travelling tripper, designed to run backwards and forwards over a track 168 feet in length carried, by the side of and above the coal-bunkers, on brackets bolted to the belt-stringers of the conveyor staging; the coal falling over the head end of the belt drops on to a side shoot fitted to the tripper and is deposited in the coal-bunkers. This belt, 16 inches in width and 245 feet in length between pulley-centres, runs at 400 feet per minute and has a carrying-capacity of 20 tons per hour.

The coal-bunkers, carried by the tie-beams of the roof-trusses, extend the full length of the boiler-house, above the boilers and superheaters, and have a storage-capacity of 100 tons.

Boiler-House.—The boiler plant (Figs. 1, Plate 4) consists of ten Heine water-tube boilers, rated at 250 HP. each but having an actual maximum capacity of close on 400 HP. The boilers are designed for a working pressure of 160 lbs. per square inch and have each a heating-surface of 2,150 square feet and a grate-area of 66 square feet; and their evaporative capacity, based on a consumption of 21 lbs. of coal per square foot of grate-area per hour with an evaporation of 6 lbs. of water per pound of coal burnt, is 8,316 lbs. of water per hour.

The boilers are arranged in pairs, and work in conjunction with four Davey-Paxman independently-fired superheaters, grouped together at the end of the range of boilers and so arranged that any one superheater can be cut out for repairs, etc., without in any way interfering with the working of the remaining three. Each superheater has 1,332 square feet of heating-surface and a grate-area of 15 square feet, and any three together are capable, with a consumption of 2,000 lbs. of coal, of adding 250° F. of superheat to 70,000 lbs. of steam per hour.

Both boilers and superheaters are equipped with Juke chain-grate stokers, two to each boiler and one to each superheater, each stoker being fitted with a hopper having an adjustable gate, enabling a layer

of coal of any desired thickness to be fed on to the grate, and supplied with coal by gravitation as required through a shoot from the storage-bunkers overhead. The stokers are driven by belts from a line of shafting, carried by the tie-beams of the roof-trusses, which is actuated through a belt-drive by a short counter-shaft driven by a 25-HP. motor. There are two of these motors—one acting as a stand-by—situated on the boiler-house floor, each controlled by a speed-regulating rheostat capable of reducing the speed of the motor 25 per cent. below normal by means of resistance inserted in series with the armature, and of increasing the speed 25 per cent. above normal by means of resistance inserted in series with the field-magnet winding. This rheostat, operated by a hydraulic regulator designed for a normal steam-pressure of 160 lbs. per square inch, is actuated by steam from the main steam-pipe, and is arranged to act on a variation of $\frac{1}{2}$ lb. per square inch in the boiler-pressure.

The ashes fall from the head ends of the stokers into small storage-bins, and are discharged as required on to a steel plate conveyor, after being first thoroughly quenched by means of a water-service fitted for that purpose above the shoots leading from the ash-bins. This conveyor, which is 18 inches in width and 225 feet $1\frac{1}{2}$ inch in length between the centres of the tumbler-shafts, and has a capacity of 5 tons of ashes per hour, runs horizontally for a distance of 199 feet in a trench below the front of the boilers before inclining upwards at an angle of 12° to discharge the ashes on to a shoot leading to the boot of the ash-elevator, and is driven by a quarter-twist belt-drive from the stoker line-shafting. The ash-elevator is of the enclosed bucket-type and lifts the ashes through a vertical height of 36 feet to discharge them on to a shoot, where they are again treated with water to ensure their being totally quenched before being deposited in two storage-bins, having a total capacity of 60 tons, situated immediately above conveyor H, the first section of the main waste-belt, and provided with doors and shoots for feeding the ashes as required on to this belt. The elevator is driven at its head end by a chain-and-sprocket-wheel drive from a short counter-shaft which receives its motion by bevel-gearing from the tumbler-shaft at the delivery end of the ash-belt.

The main flue from the boilers and superheaters is arranged in connection with a Green economizer and an induced-draught plant. The economizer, designed for heating the feed-water for a 3,500-HP. boiler-plant, and for a working pressure of 160 lbs. per square inch, is built up of 1,200 tubes arranged in two sections, each section consisting of 600 tubes, in sixty nests of ten tubes, connected together in the ordinary way and served by two lines of scraper-

gearing placed on the top of the economizer. Between the two sections there is a reserve flue, and the three flues are fitted with a system of dampers, enabling the gases to be diverted through either of the two sections of the economizer, or to be by-passed direct to the induced-draught fans and smoke-stack whenever it becomes necessary to close down either section of the economizer for cleaning or repairs.

The induced-draught plant consists of two three-quarter-housed fans, 12 feet in diameter, each capable of dealing with the gases generated by a maximum coal-consumption of 14,000 lbs. per hour, and of creating, when running at 200 revolutions per minute, a vacuum equal to 2 inches on the water-gauge; and of a smoke-stack 10 feet in diameter and 60 feet in height. The fans are fitted with water-cooled bearings next to the stack and are run by belts from a counter-shaft driven by the two 66-HP. motors, one acting as a stand-by, situated on the economizer-house floor. This counter-shaft also drives the economizer scraper-gear and is fitted with two clutches so arranged that, whilst the scraper-gearing is always running, either fan or motor can be used. The vacuum is automatically regulated by a speed-controlling rheostat fitted to each motor, capable of reducing the speed of the motor 50 per cent. below normal, or of increasing it 25 per cent. above normal, and actuated by the hydraulic regulator already referred to as governing the motors driving the chain-grate stokers and the ash-belt and elevator.

The 7-inch steam-pipe from each boiler is coupled up to a 12-inch main arranged so as to enable the saturated steam from the boilers to be either by-passed direct to the engine-room or first passed through one or more of the superheaters. This section of the main steam-pipe running through the boiler-house and pump-room is fitted with an expansion-bend and a steam-separator.

The boilers are supplied with feed-water by three compound Weir pumps, each capable of delivering 8,000 gallons of feed-water per hour through the six feed-water heaters, the feed-water filter and the economizer, against a boiler-pressure of 160 lbs. per square inch. The feed-water pipe-line is so arranged that the feed-water can be pumped either directly to the boilers from the hot-well, or first passed through either the feed-water heaters or the economizer, or through both feed-water heaters and economizer.

Arrangements have been made in the boiler-house for complete boiler-tests to be carried out. The feed-water pipe-line is fitted with a hot-water meter and with recording thermometers, a thermometer being inserted in the pipe-line where it enters the boiler-house in order to determine the temperature of the feed-water as it leaves

either the hot-well or the feed-water heaters, and also where the pipe-line enters and where it leaves the economizer, to determine the amount of heat added to the feed-water by the flue-gases. In the flue from the superheaters, in the flue from the boilers, and in the main flue between the economizer and the smoke-stack, electric resistance-recording thermometers have been fitted; whilst two electric temperature-recorders have also been placed in the main steam-pipe to determine the temperature of the steam before and after leaving the superheaters. It is expected that the feed-water leaving the hot-well at about 90° F. will be raised to 150° F. by the feed-water heaters, and to about 250° F. by the economizer, and that the gases leaving the superheaters at about 600° F., and the boilers at about 550° F., will be reduced during their passage through the economizer to about 200° F. Actual working results have shown a feed-water temperature on leaving the economizer of 240° F. to 250° F.

Engine-Room.—The central engine-room (Figs. 1, Plate 4), a steel-framed building covered with galvanized corrugated iron, is 409 feet 4 inches in length by 60 feet in width in inside measurements, and 28 feet in height from floor to eaves. A crane-track, bolted to heavy iron girders, supported by brackets riveted to the side-wall columns, extends along its entire length, and carries a 15-ton hand travelling-crane. The floor is of granolithic paving, and the engines all rest on capstones of dressed freestone raised 6 inches above the floor-level, and are bolted down to solid foundations of coursed rubble.

The two engines designed to provide alternative means of driving the mill-shafting are situated at the west end of the engine-room. They are by Messrs. Hick, Hargreaves and Company, Limited, and are horizontal single-tandem compound-condensing Corliss engines fitted with valve-gear of the Inglis and Spencer pattern. The high-pressure and low-pressure cylinders are 20 inches and 39 inches in diameter respectively by 4 feet 6 inches stroke, and the full economical load when running at the normal speed of 70 revolutions per minute is 720 I.H.P. The engines are supplied with steam at a pressure of 135 lbs. per square inch and a superheat of 150° F. at the engine stop-valve, the steam-consumption under normal conditions being 13·43 lbs. per I.H.P.-hour. The two engines and all their parts are alike and interchangeable, with the exception that the "A" engine has a plain fly-wheel 20 feet in diameter and weighing 25 tons, whilst the "B" engine has a rope-driving fly-wheel of the same diameter and weight grooved for twelve 2-inch ropes. The "A" engine is coupled directly by a

claw-clutch to the mill-shafting, whilst the "B" engine drives a 20-foot rope-pulley keyed to a sleeve-shaft through which the mill-shafting runs, which can be coupled up to the shafting by two steel claw-clutch couplings when the "A" engine has to be stopped for overhauling or repairs.

In line with the mill-engines is situated the electric power-plant, consisting of three high-speed dynamo-sets run in parallel, each set composed of one "Belliss" three-crank, triple-expansion, quick-revolution, vertical condensing engine, with cylinders 14 inches, 20½ inches, and 30½ inches in diameter by 14 inches stroke, developing 500 brake-HP. when running at 360 revolutions per minute, with steam superheated to 508° F. and having at the engine stop-valve a pressure of 135 lbs. per square inch. The mechanical efficiency at full load is 92 per cent., and the steam-consumption under the foregoing conditions and with a vacuum of 20 inches in the exhaust-pipe is 13·8 lbs. of steam per I.H.P.-hour. The engines are extremely well governed, the governor being so sensitive that when full load is thrown on or off the permanent variation of speed between full-load and no load does not exceed 1½ per cent. from the mean. Each engine is coupled directly to a 350-kilowatt, continuous-current, shunt-wound, eight-pole dynamo, by the General Electric Company, London, bolted to an extension of the engine bedplate, and having an output when running at 360 revolutions per minute of 1,400 amperes at a pressure of 250 volts. Sufficient space has been left to admit of the erection of two additional dynamo-sets at any future time if required.

The main switchboard, placed parallel to the side wall of the engine-room, opposite to the A mill-engine, is about 42 feet in length, consists of seventeen panels of polished black marble secured to a strong iron framing bolted to a masonry foundation, and has each end enclosed by sliding doors of iron lattice-work. The panels are grouped as follows :—at the west end, four lighting distribution-panels ; in the centre, five generator-panels ; and at the east end, eight power distribution-panels.

Beyond the electric generators is the main air-compressing plant, consisting of two compressors by Messrs. Walker Brothers, Wigan, each compressing the air in two stages, with intermediate cooling. The larger engine, a horizontal, cross-compound, condensing engine fitted with a steam-jacketed intermediate receiver and with the high-pressure steam- and air-cylinders and the low-pressure steam- and air-cylinders arranged tandem, has been designed when running at its normal speed of 50 revolutions per minute to operate fifty 3½-inch air-drills, allowing each drill 130 cubic feet of free air per

minute at a temperature of 65° F. When running at its normal speed with steam having a pressure of 135 lbs. per square inch at the stop-valve and a superheat of 150° F., and with a vacuum of 20 inches in the exhaust-pipe, the engine develops 1,132 I.H.P., with a steam-consumption of less than 14 lbs. per I.H.P.-hour and compresses 6,500 cubic feet of free air per minute to a working-pressure of 80 lbs. per square inch at the receiver. The steam-cylinders are 28 inches and 55 inches in diameter by 5 feet stroke, and are fitted with steam- and exhaust-valves of the "Reynolds" Corliss type, the cut-offs on both cylinders being controlled through the medium of a trip-gear actuated by the governor, and also, by means of an air-regulating device, by the air-pressure in the air-receiver: the cut-off of the low-pressure cylinder is also adjustable by hand. The air-cylinders are 30 inches and 48 inches in diameter by 5 feet stroke and are fitted with air-valves of the makers improved "Accessible" type. The fly-wheel is 20 feet in diameter and weighs 28 tons. A circulating-pump of the horizontal type, the plunger keyed direct to the tail-rod of the low-pressure piston, supplies the circulating-water to the water-jackets of the air-cylinders and to an intermediate cooler built up of steel plates, and having a cooling-surface of 1,000 square feet. This engine can, if necessary, by being run at a higher speed, increase its output by 50 per cent. and operate a maximum of seventy-five 3½-inch air-drills. The smaller compressor, which is in every respect similar to that just described, has been designed to operate twenty-five 3½-inch air-drills, and at its normal speed of 50 revolutions per minute has an output of 500 I.H.P. The steam-cylinders are 20 inches and 44 inches in diameter, and the air-cylinders 20½ inches and 44 inches in diameter, all by 4 feet stroke, whilst the air-cooler has a cooling-surface of 500 square feet and the fly-wheel is 16 feet 3 inches in diameter and weighs 18 tons.

Beyond these compressors is a first-motion double conical drum-hoist by Messrs. Hick, Hargreaves and Company, Limited, having specially-designed drums driven by cross-compound Corliss condensing engines fitted with an intermediate receiver of the "thoroughfare" type, all the steam to the high-pressure cylinder passing first through the receiver and thus heating the exhaust steam from that cylinder before it passes to the low-pressure cylinder. The engines are designed for working an incline making an angle of 26° with the horizontal and 5,000 feet in length, the load being made up of 7 tons of rock, a skip weighing 4½ tons, and a taper-rope having a minimum diameter of 1½ inch at the bottom end and tapering upwards so that the factor of safety is at no point less than eight.

The engines, although ordinarily working the ascending and descending skips simultaneously, can easily work either compartment independently. The acceleration after starting is such that the full speed of 3,500 feet per minute, corresponding to an engine-speed of 55 revolutions per minute, is reached about the time that the hoisting-rope fills the conical part of the drum. The cylinders are 30 inches and 48 inches in diameter by 5 feet stroke, and under the conditions already referred to in connection with the other engines they develop 1,100 I.H.P. The cylinders are fitted with valve-gear of the "Inglis and Spencer" type, actuated by bevel-gearing from the crank-shaft, reversing being effected by a "jack-in-the-box" arrangement with four bevel-wheels. A cross-shaft is driven by this gear, and is fitted with eccentrics keyed to its ends, operating the usual wrist-plates for the Corliss gear of the high-pressure and low-pressure cylinders. The special advantage of this gear is that the full stroke of the eccentrics is always maintained, thus ensuring under all conditions the engagement of the trips. The governor is connected with the trips of the two valve-gears through a slotted rod in such a way that, when the engine is below its normal speed and the governor down, the cut-off may be shortened by the throttle-valve lever on the driver's platform, but on the engine reaching full speed and the governor rising, the governor cannot be prevented by the driver from acting on the tripping-arrangement and so keeping the speed of the engine within the intended limits.

Each cylinder is provided with a throttle-valve controlling the steam admission. These two valves, together with the trip-gear, are actuated by one lever from the driver's platform in such a way that when the lever is in one extreme position the throttle-valves are closed and the cut-off in each cylinder is at its longest; movement of this lever first opens the throttle-valves and then shortens the cut-off, until, when it is in the other extreme position, the throttle-valves are wide open, but the bits cannot engage, and so no steam can enter the cylinders. The cylinders are also fitted with by-pass valves worked simultaneously by one handle from the driver's platform. In order to ensure the ability of the engines to start at any point of the stroke, an intercepting-valve, operated by a hand-lever on the driver's platform, is inserted in the pipe-line exhausting from the high-pressure to the low-pressure cylinder, enabling steam to be admitted to the latter, the valve being so designed as to change over automatically to compound working as soon as the pressure of the steam exhausted from the high-pressure cylinder reaches a predetermined point. The depth-indicators are of the clock-type having two hands, the short hand making one

revolution during the whole "wind" of 5,000 feet, whilst the long hand is arranged to remain stationary until the skip is within 100 feet of the tip, when it comes into action, and during the last 100 feet makes one complete revolution, enabling the driver to time the stopping of the skip with great accuracy. The indicators are also arranged to give such bell-signals as are called for by the Transvaal Mining Regulations. In connection with the depth-indicators is a safety stop, worked by a cam on the wheel driving the long hand. At a predetermined amount of over-wind this cam, coming in contact with a lever, disconnects the hand-levers on the driver's platform controlling the post-brakes, the valve trip-gear and the by-pass valves, from their connections, and permits a system of lever-weights to apply the post-brakes, to release the valve trip-gears, so allowing the dash-pots to close the steam-valves, and to open both by-pass valves, thus bringing the engine immediately to a standstill. These safety stop-connections are so designed as to allow the free working of the hand-levers under normal conditions. In actual practice this appliance brings the engine to a standstill in half a revolution when running at full speed.

Each drum consists of a conical part, having a diameter, measured to the centre of the rope, of 12 feet at the small end and 20 feet at the large end, and winding about 1,250 feet of rope, in addition to the number of turns required for gripping, and of a parallel part, 20 feet in diameter, measured to the centre of the rope, and holding 3,750 feet of rope in two layers. A supplementary drum, carrying 300 feet of spare rope, is placed inside and attached to the main drum, and is fitted with internal spur-gearing, enabling it to be revolved by hand independently of the main drum, when, owing to the periodical cutting-off of testing-pieces, it is necessary to lengthen the rope. On the conical part of the drum the rope lies in deep retaining-grooves, the section being carefully designed so that the rope does not rub against the sides of the grooves, whilst the parallel part of the drum has grooves of a depth equal to about one-third the diameter of the rope, so pitched that the ropes will not chafe against the previous layer during winding. Each drum, built up of three sets of bosses and arms and of cast-iron grooved segments, runs free upon the crank-shaft and is provided with a powerful band-clutch, consisting of a massive brake-pulley keyed and bolted to the crank-shaft and fitted with duplicate brakes of steel band lined with wood, operated by a toggle-gear, actuated, through a sleeve moving endwise on the crank-shaft, by one of the auxiliary clutch-engines. Each drum has bolted to it a heavy cast-iron rim forming the races for the post-brakes, which consist of two

curved beams, built up of boiler-plate and angle-bars, lined with wooden blocks, suspended on pendulum-links and provided with suitable stops and the necessary levers, weights, etc., for working them. There are six auxiliary engines:—two working the drum-clutches, two the post-brakes, one the two disk-crank brakes, and one the reversing-gear. The brakes and the reversing-gear are operated by the fall of heavy weights, the engines simply lifting these weights and holding them in suspension until required; whilst the drum-clutches are actuated directly by their engines. Each auxiliary engine has two cylinders, arranged tandem—the lower being a steam-cylinder, and the upper a cylinder filled with oil and connected to an oil-reservoir, acting as a buffer to prevent shock and jar on the application of the brakes, and on reversing the engine. On the driver's platform are conveniently grouped all the hand-levers, etc., required for controlling the engine, namely, one handle operating the high-pressure and low-pressure throttle-valves and trip-gears, one the intercepting-valve, one the high-pressure and low-pressure by-pass-valves, one the reversing-gear, two the post-brakes, two the drum-clutches, and one foot-pedal the disk-crank brakes.

The steam-pipes in the engine-room are of lap-welded steel tubing and have the flanges forged on. The main pipe-line is provided with three expansion-bends and two steam-separators, and the branch-pipes to the engines are fitted, close to the engine stop-valves, with both dial and mercury thermometers. All the cylinder drains from these engines are led to two subsidiary cylinder-oil collecting-tanks, and the collected oil and water is pumped automatically by two steam-lifters to the main oil-drain running from the grease-separators of the condensing-plant to the main cylinder-oil collecting-tank in the pump-room. Complete arrangements have also been made for saving all machine-oil and for collecting and carrying it when necessary to the machine-oil filtering-plant in the pump-room. The engines have all been fitted with a very complete system of gauges and automatic recorders, enabling exhaustive tests to be carried out with each one of them.

The remaining engines have been erected for some years, and consist of an ordinary geared winder with two high-pressure cylinders $14\frac{1}{2}$ inches in diameter by 28 inches stroke and having two parallel drums 8 feet in diameter; a cross-compound two-stage air-compressor with intermediate cooling, by Messrs. Walker Brothers, Wigan, fitted with slide- and expansion-valves and having steam-cylinders $16\frac{1}{2}$ inches and 30 inches in diameter and air-cylinders $19\frac{1}{2}$ inches and 31 inches in diameter, all by 3 feet stroke; and a pumping-engine of the ordinary slide- and expansion-valve type

with a single cylinder 16 inches in diameter by 32 inches stroke, transmitting motion to the pump-rods by means of a spur-wheel and pinion. A surface-condenser and circulating-water pump are provided for dealing with the exhaust-steam [from this air-compressor.

The exhaust-steam from the eight engines first described is led by a system of exhaust-pipes to a condensing-plant situated between the electrical generating-plant and the north wall of the engine-room. These pipes are of light lap-welded steel tubing with the flanges screwed on, proportioned so that the velocity of the exhaust-steam shall under no conditions exceed 6,000 feet per minute, and fitted with a system of valves enabling the steam from any one engine to be turned into a single condenser. There are five combined surface-condensers and feed-water heaters, each condenser, of the rectangular Admiralty pattern Volz-type, having superimposed on it a feed-water heater. The condenser-tubes, $\frac{3}{4}$ inch in external diameter by 10 feet in length between the tube-plates and No. 16 S.W.G. in thickness, have a cooling-surface of 2,400 square feet in each condenser; whilst the feed-water heater tubes are $\frac{3}{4}$ inch in external diameter by 10 feet in length between the tube-plates and No. 11 S.W.G. in thickness, and have an additional cooling-surface of 800 square feet and a corresponding heating-surface. These heaters have been erected not so much with the primary object of heating the feed-water, the economizer-plant being sufficient for that purpose, but with the intention of effecting as great a saving in the circulating-water as possible. Each condenser is designed to deal with 15,000 lbs. of exhaust-steam per hour, allowing about 6.5 lbs. of steam per square foot of condensing surface per hour; and is supplied with 72,000 gallons of water per hour by the circulating-water plant, allowing 4.8 gallons of circulating-water per pound of steam per hour. The maximum vacuum that can be obtained in the condensers is never more than 21 inches, owing to the situation of the mine at an altitude of 5,500 feet above sea-level. In front of the condensers are five Edwards three-throw air-pumps, each pump serving one of the condensers and dealing with 15,000 lbs. of exhaust-steam per hour. These pumps, which have a very high mechanical efficiency and which dispense with foot- and bucket-valves, have cylinders 14 inches in diameter by 12 inches stroke, run at 150 revolutions per minute, and are each driven through spur-gearing by a hide pinion keyed to the armature-shaft of a totally enclosed four-pole motor of 15 brake-HP. The great advantage of this independently-driven condensing-plant is that the main engines are effectually relieved from the more or less fluctuating load of the air-pumps, and a more even turning is

ensured. A feed-water measuring-tank, fitted complete with an automatic apparatus for recording the quantity of water delivered by the air-pumps, with a recording thermometer and with a weir discharging into the hot-well, is placed in the pump-room and is so arranged that any one or more pumps can discharge into it, the remainder being by-passed direct to the hot-well. This arrangement, together with the system of valves in the exhaust-pipes, enabling the exhaust from any engine to be turned into a single condenser, permits of very complete combined engine and boiler tests being carried out. The hot-well is 12 feet square by 4 feet in depth, and is fitted with a 2-inch make-up water-service automatically supplying the deficiency, usually amounting to about 10 per cent., in the water returned by the condenser air-pumps to the hot-well and boiler feed-pumps.

In each of the four main exhaust-pipes going to the condensing-plant, a Brooke oil-separator is placed, and between these separators and each condenser is inserted a 13-inch relief-valve and pipe automatically exhausting the steam to atmosphere should the pressure in the condensers rise above a predetermined limit. Three of the separators have each a capacity of 22,500 lbs. of exhaust-steam per hour, and the remaining separator has a capacity of 15,000 lbs. Each separator is provided with a Brooke automatic oil-discharger delivering the separated oil to the main cylinder-oil collecting-tank in the pump-room, where complete cylinder- and machine-oil filtering-plants have been installed. The cylinder-oil, both from the cylinder-drains, as previously described, and from the grease-separators, is discharged automatically into the main cylinder-oil collecting-tank, and from there is raised automatically by a steam lifter into two oil-settling tanks. Here the oil separates from the condensed steam, runs by gravity into two filters, each having a capacity of 140 gallons a week, and is delivered ready for use to two oil-cabinets standing on the pump-room floor. The machine-oil filtering-plant is exactly similar, except that the two filters have each a capacity of 250 gallons per week, and that the oil has to be carried by hand from the various engines to the machine-oil collecting-tank. The feed-water pipe-line is arranged with three through-valves to each feed-water heater, permitting any or all of the heaters to be cut out as required. Between the pumps and the feed-water heaters a Reeves duplicate filter is inserted in the pipe-line, and between it and the pumps is a by-pass and dead-weight safety-valve automatically by-passing the feed-water to the pipe-line running direct from the feed-water heaters to the economizers or boilers in the event of the pressure in the pipe-

line to the filters or feed-water heaters rising above a predetermined limit.

Circulating-Water Plant.—Advantage has been taken of a dam situated near the engine-room by utilizing it both as a source of supply for the circulating-water and also as a cooling-pond. From this dam, which has an average water-area of 50 acres, and an average depth of 5 feet, a tunnel, 700 feet in length, brick-lined, and divided into two compartments by a brick division-wall, has been driven horizontally to the bottom of a shaft sunk close to the condenser-plant, and serves as the suction and delivery of the circulating-water pumps. At the dam end the two compartments of the tunnel have been fitted with sluice-gates, and the outlet-branch has been carried for some distance along the side of the dam, so as to discharge the heated water at a sufficient distance from the intake. The surface of the dam is 40 feet below the highest point of the condenser-plant, and as the friction of the pipes and condensers is equal to an extra head of 6 feet, the total head against which the pump has to act in starting is 46 feet; as, however, the suction due to the siphon-action of the condenser-discharge is equal to 15 feet, the actual working head is only 31 feet. The plant has been designed to lift 350,000 gallons of water per hour, and, allowing 50 per cent. efficiency in the pumps, the motors have been designed when running at 480 revolutions per minute to develop 163 brake-HP. for short periods, to enable them to start up the pumping-plant, and 100 brake-HP. continuously for constant running when the suction due to the siphon action of the condenser-discharge has started. The plant consists of a 30-inch centrifugal pump and motor on one bedplate, and a 30-inch centrifugal pump, motor and turbine on another bedplate, the separate pump and motor being intended to serve as a stand-by to be used in case of a breakdown in the turbo-pump combination. The turbo-pump combination has been designed to utilize the potential energy of the water as delivered from the condensers, and to accomplish this a sump has been built on the surface to receive the discharge from the 8-inch delivery-pipes of the condensers. From this sump a 21-inch pipe leads the water with a working head of 25 feet direct to a twin Lunedale turbine, developing, when running at 480 revolutions per minute, and allowing the turbine an efficiency of 75 per cent., about 33 brake-HP. The turbine is coupled direct to one end of the armature-shaft of the motor, and the other end of the armature-shaft is coupled to the centrifugal pump. By this arrangement a saving of about 33 per cent. of the total power otherwise required to drive the pump is effected. A 21-inch main from the pumps

supplies an 8-inch branch to each condenser, and a 6-inch branch feeding the suction of the circulating-water pumps of the two compressors. The return-water from the water-jackets of the air-cylinders of the two compressors and from the intermediate air-coolers is also led to the sump,

ORE REDUCTION-WORKS.

Central Headgear.—The main haulage-shaft, which is situated in the centre of the outcrop of the reef running through the Company's property, will be ultimately sunk to a length of 5,000 feet at an inclination of about 26° to the horizontal; it is served by a headgear which has been designed for hauling from the four winding-compartments of the shaft, and for raising and lowering heavy pump-fittings, etc., in the fifth compartment. This headgear has a total storage-capacity of 1,000 tons, made up of 850 tons in the two ore-bins, and 150 tons in the waste-rock bin. Four tracks of 4-foot 6-inch gauge, spaced 6 feet 2 inches apart, centre to centre, and laid with steel rails weighing 45 lbs. per yard, run up from the shaft to the headgear tips. The tip has been so designed that wheels of normal tread for the track-rails employed can be used on both the front and rear axles of the skips, enabling full advantage to be taken of the width of the winding compartments, and permitting the use of skips of maximum carrying capacity. At the tip the track-rails, after bending down, have their lower ends curved to form a segment of a circle having a radius equal to that of the skip-wheels. As the skip approaches the tip, its front wheels run down into these segments, and remain there, whilst the rear-wheels, continuing to move forward, come in contact with the steel-lined upper edges of the cheek-pieces bolted to the headgear-bridges. The skip can now be pulled forward in its reversed position for some 21 feet, the rear wheels running along the top of the cheek-pieces whilst the front wheels move between the lower edges of the cheek-pieces and angle-bar rails fixed parallel to them, providing a safeguard against overwinding. In returning, the skip travels back in the reversed position until the front wheels again engage in the segments previously referred to, where they remain until, the rear-wheels having fallen on to the track rails, the skip can again run down the shaft.

Two sizes of skips are in use, the larger size, having a capacity of about 7 tons, being intended for use with the new 1,100-HP. conical drum-hoist for raising the ore at high speeds from the deeper levels of the mine, and the smaller size, having a capacity of

3 tons, for use with the small geared winding-engine serving the upper levels of the mine, and for raising and lowering men and tools. The headgear-pulleys are also of two sizes, viz.:—two pulleys 12 feet in diameter for use with the large skips, and three pulleys 8 feet in diameter, of which two are for use with the small skips and one is for raising and lowering pump-rods, fittings, etc., in the pump-compartment of the shaft; some of the track sleepers have been extended beyond the main incline-legs, and carry rollers to support the rope working the pump-compartment of the shaft. The rock dumped from the skips falls on to steel-lined shoots running across the main ore-bin to the waste-rock bin, and provided with heavy steel doors, fitted above the main ore-bin, enabling the contents of the skips to be dumped either in the main ore-bin or in the waste-rock bin. Each door is operated from the ground-level at the back of the headgear by means of a wire-rope running over guide-pulleys, and fitted with a balance weight. In combination with the main ore-bin, with its storage capacity of 650 tons, a haulage ore-bin designed to hold 200 tons has been built, into which the ore raised from the "East" and "West" three-compartment shafts, and conveyed in trucks by mechanical haulage to the three tracks laid on the haulage-bin caps, is dumped. The fourth track, outside the bin, is for the return of empty trucks. The waste-rock bin is fitted with four doors and shoots for discharging the waste-rock as required into trucks running along rails, bolted to the waste-rock platform and to runners carried on trestles, up to a subsidiary waste-rock dump, where the trucks are dumped. The combined ore-bins are fitted with six hoppers and movable shoots designed for feeding the ore uniformly at any desired rate on to Conveyor A, a Robins belt-conveyor running immediately below the bin-shoots, and raising the ore up to the trommel section of the crusher-station.

Conveyor from Headgear-Bins to Crusher-Station.—Conveyor A (Figs. 1, Plate 4), carrying the rock from the headgear to the crusher-station, runs horizontally immediately below the headgear ore-bins, then curves round a segment of a circle 250 feet radius connecting the horizontal portion to an incline-portion rising at an angle of 15° , and passes on up to the trommel section of the crusher-station. The incline-portion of the belt is carried by two light steel Linville trusses in two spans of 80 feet each having their intermediate ends supported by a steel trestle built up of angle-bars and stiffened with angle-bar bracing. The belt is 30 inches in width, travels at a speed of 200 feet per minute and has a carrying-capacity of 280 tons per hour. The total length of the

belt, between the centres of the pulleys, is 278 feet, and the height to which the ore is raised is 47 feet.

Crusher-Station.—The crusher-station (Fig. 3, Plate 4) may be divided into three main sections, namely:—the trommel section, including the main trommel, the No. 1 “fines” bin, and the “coarse” and “intermediates” ore-bins; the sorting-floor and waste-rock bin section, including the “coarse” and “return intermediates” sorting-belts, the “return intermediates” belt, and the “return intermediates” trommel; and the crusher section, including the No. 2 “fines” bin and the “return intermediates” bin.

The rock carried from the headgear ore-bins by conveyor A is discharged on to a shoot and delivered directly to the main trommel, where it is subjected to a double process, the upper section of the trommel acting as a screen to remove “fines,” and the lower section acting as a washer, freeing the “coarse” rock from dust and dirt and so facilitating sorting. The trommel is inclined at an angle of 10° and is driven at a speed of 10 revolutions per minute by a chain-and-sprocket drive and toothed gearing from the 50-HP. motor driving the head end of conveyor A. The upper section, 9 feet in length and 5 feet in diameter, is formed of plates $\frac{5}{8}$ inch in thickness perforated with holes 2 inches in diameter, spaced $2\frac{3}{4}$ inches apart, centre to centre, whilst the lower section, which is also 9 feet in length and 5 feet in diameter, is built of plates $\frac{1}{2}$ inch in thickness, pierced with holes $\frac{3}{4}$ inch by $\frac{3}{4}$ inch, spaced $\frac{1}{2}$ inch apart. Water supplied by a 4-inch perforated pipe, and distributed evenly over the rock on its passage through the lower section of the trommel, drains through the perforated plate, is caught by a collecting-box fitted immediately below the trommel, and is then led by a branch launder to the main launder running outside the building and carrying the washings from the “return intermediates” trommel, as well as from the main trommel just described, to two settling-tanks situated outside the crusher-station above the No. 1 “fines” belt-conveyor E. The screening section of the trommel removes 40 per cent. of the total quantity of rock passing through it, which falls as “fines” directly into a bin having a storage-capacity of 450 tons, situated immediately below the trommel and known as the No. 1 “fines” bin. The remaining 60 per cent. or “coarse” rock, on issuing from the trommel, passes first over a “dripper” or short grating built of 1-inch square bars on edge, spaced $1\frac{1}{2}$ inch apart, centre to centre, and then falls directly on to the main grizzlies, formed of manganese steel bars 1 inch by 4 inches by 14 feet in length, spaced $3\frac{1}{2}$ inches apart, centre to centre. The grizzlies, two in number, are set back to back at an

inclination of 40° to the horizontal and are placed 10 inches to one side of the centre-line of the main trommel to allow for the throw given to the rock by the revolving trommel. The rock passing over the grizzlies is sorted into two sizes, all less than $2\frac{1}{2}$ -inch cubes, an average of about 40 per cent. passing between the bars and falling into the two "intermediates" bins, whilst the remainder passes on into the two "coarse" bins. These four bins have no storage-capacity and simply act as feeder-bins for the picking-belts. A hand-power travelling-crane of 8 tons capacity is provided in this section of the crusher-station; and in the main trommel-platform trap-doors are fitted allowing a clear lift to be made from a railway-siding carried under this section of the crusher-station, up to the trommel-platform. The lower portion of the main framing of the trommel-section has been utilized for supporting a section of the mechanical haulage-track conveying the ore from the West shaft to the haulage ore-bin in connection with the headgear at the Central shaft.

A platform inclined at an angle of 16° runs from directly below the "coarse" and "intermediates" bins up to the sorting-floor, which is carried by the waste-rock bin-caps and slopes upwards at an inclination of 10° from this platform to the sorting-belts platform, situated above the crusher-platform. The sorting-floor carries four sorting-belts, two for "coarse" and two for "intermediates," and provides on both sides of each belt nine openings leading directly to the waste-rock bins, and floor-space for two boys to each opening; provision has thus been made for thirty-six boys to work on each belt, or a total of 144 boys on the sorting-floor. The "coarse" and "intermediates" sorting-conveyors, known respectively as conveyors B and conveyors C, are of the Robins type, and proceed at an inclination of 16° from the "coarse" and "intermediates" bins up to the sorting-floor, and at an angle of 10° over this floor up to their head ends on the sorting-belts platform. The "coarse" belts, 36 inches in width and 86 feet 6 inches in length between the pulley-centres, driven by 10-HP. motors, travel at a speed of 50 feet per minute and have a capacity of 58 tons per hour; whilst the "intermediates" belts are 36 inches in width and 98 feet 5 inches in length between the pulley-centres, and, driven at a speed of 50 feet per minute by 10-HP. motors, carry 61 tons of rock per hour. These speeds can be either increased or diminished 20 per cent.

The "coarse" rock, falling from the main grizzlies into the "coarse" bins, is fed by shoots and regulating-doors at a constant rate on to conveyors B, where it passes through the first stage of

sorting, after which the remaining rock is discharged at the head ends of the belts on to shoots leading it directly to the two 30-inch by 18-inch "coarse" crushers, of the Blake-Marsden eccentric-motion type, to be broken into 3-inch cubes.

The crushed rock falls on to grizzly-bars spaced 1 inch apart and is separated into two sizes; all rock smaller than 1 inch cubes, about 5 per cent. of the total, falling between the bars as "fines" into the No. 2 "fines" bin, and the rest passing on as "return intermediates" to the "return intermediates" bin. This bin acts merely as a feeder-bin for the "return intermediates" conveyor, or conveyor D, and is fitted with a shoot and regulating-door for feeding the rock at a constant rate on to the belt. Conveyor D runs upwards between the waste-rock bins at an angle of $21\frac{1}{2}^{\circ}$ —which is found to be about the limit of inclination for rock of this size—and extends from the "return intermediates" bin to the "return intermediates" trommel. The belt is 18 inches in width and 79 feet 2 inches in length between pulley-centres, and when travelling at a speed of 300 feet per minute has a capacity of 50 tons per hour. The "return intermediates" trommel, inclined at an angle of 10° and driven at a speed of 10 revolutions per minute, through a chain-and-sprocket drive and toothed gearing, by the 15-HP. motor driving the head end of conveyor D, is carried on a platform just above the "intermediates" bins, and acts simply as a washer, cleaning the "return intermediates" from dust and dirt previous to undergoing a second sorting on the "intermediates" sorting-belts. The trommel, 3 feet in diameter and 4 feet in length, is built up of $\frac{1}{2}$ -inch plates pierced with holes $\frac{3}{8}$ inch by $\frac{3}{4}$ inch spaced $\frac{1}{2}$ inch apart, and is supplied with water by a 2-inch perforated pipe running along its full length. All washings draining through the plates are caught by a collecting-box fitted below the trommel and are led by a branch launder into the main launder previously referred to. The rock falling from the mouth of the "return intermediates" trommel joins the "intermediates," separated by the main grizzlies from the rock discharged by the main trommel, in the two "intermediates" bins, and is fed, together with the "intermediates," by means of shoots and regulating-doors, at a constant rate, on to the "intermediates" sorting-belts, where it is sorted in conjunction with the "intermediates," after which the remaining rock is discharged at the head ends of the belts, on to shoots leading direct to the "intermediates" crushers. The main trommel, as previously mentioned, delivers, as "coarse" and "intermediates," about 60 per cent. of the total rock brought to it by conveyor A, from the headgear bins at the central shaft, to the

sorting-belts, where, during the sorting, as already described, about 50 per cent. is removed as waste, amounting to about 30 per cent. of the total rock brought to the surface from the mine. The ore from the "intermediates" sorting-belts is fed by means of a system of shoots to three "intermediates" crushers, each 30 inches by 18 inches, of the Blake-Marsden eccentric-motion type, placed in line on the "intermediates" crusher platform, and so arranged that any one of them can act as a stand-by. The "intermediates" are here broken into 1-inch cubes and fall as "fines" directly into the No. 2 "fines" bin. This bin, having a storage-capacity of 750 tons, brings the "fines" storage-capacity of the crusher-station up to a total of 1,200 tons. The crushers are all driven by belts from a second-motion shaft actuated by one of the two 150-HP. motors (the other acting as a stand-by) erected in the motor-room on the ground-floor of the crusher-station; each driving-pulley on the second-motion shaft is fitted with a Seymour friction-clutch operated by a hand-wheel mounted on a clutch-standard on the crusher-platform, enabling any crusher to be stopped as required. This section of the crusher-station is provided with an 8-ton hand-power travelling-crane for the easy handling of the crusher parts. The two waste-rock bins, situated immediately below the sorting-floor and separated from each other by the platform supporting the "return intermediates" belt, have a total storage-capacity of 1,500 tons, and are each fitted with three shoots designed for feeding the waste-rock at any desired rate on to the waste-rock belt-conveyor G, and with a large baffle-plate to prevent rock being dropped from the sorting-floor through the shoots directly on to the belt. Similar shoots have been fitted in the two "fines" bins, two in the No. 1 bin and three in the No. 2 bin, and feed the "fines" at any desired rate on to conveyor E, the "fines" conveyor to the mill. The main water-service to the crusher-station is brought by a 5-inch branch-pipe taken off the 9-inch main from the high-level return-water supply-tank.

Waste-Rock Belt.—Conveyor G runs horizontally below the waste-rock bins and carries the waste-rock from these bins to deliver it through a shoot on to conveyor H. This belt, the first section of the main waste conveyor, runs at right-angles to and below the head end of conveyor G, which it drives by bevel-gearing from its tail-pulley, the belt itself transmitting the necessary power from the 50-HP. motor driving its head end. The waste-rock belt, 30 inches in width and 52 feet 6 inches in length between pulley-centres, travels at a speed of 200 feet per minute, and has a carrying-capacity of 112 tons per hour.

"Fines" Conveyor from Crusher-Station to Mill.—The "fines"

conveyor, or conveyor E, runs under the crusher-station along its entire length, sloping downwards at an angle of 5° from below the No. 1 "fines" bin, and passing under conveyor G to below the No. 2 "fines" bin; here it bends upwards, and, passing round a curve of 250 feet radius, reaches the ground-level and, after running below the two settling-tanks previously referred to, proceeds upwards at an angle of 18° to its head end, carried by two light steel Linville trusses in two spans of 60 feet each, Figs. 2, Plate 4. The intermediate ends of the trusses are supported by a light steel trestle built up of angle-bars and strengthened by angle-bar bracing, and the upper end of the top truss is supported by the wooden staging carrying the motor-room containing the 50-HP. motor which drives the head end of conveyor E and the tail-end of conveyor F. The belt is 24 inches in width and 365 feet in length between pulley-centres, and, travelling at a speed of 350 feet per minute, raises the "fines" through a vertical height of 58 feet and transports a maximum of 168 tons per hour from the "fines" bins to conveyor F, feeding the mill-bins.

Stamp-Mill.—The stamp-mill (Figs. 5, Plate 5) will be best described by following the course of the ore from the time it is delivered as "fines" by conveyor F to the mill-bins until it leaves the mill as "tailings" by the main launder to the tailings-wheel.

The "fines" deposited in the storage-bins of the crusher-station are fed by the bin-shoots on to conveyor E, and are thence discharged through a shoot on to conveyor F, running at right-angles to conveyor E below its head end; from this conveyor, after passing through a weighing-room, they are distributed equally along the full length of the mill ore-bins by means of an automatic tripper. The weighing-room extends from the motor-room to the mill, and is built on a continuation of the top floor of the mill, supported by trussed beams extending from the staging carrying the motor-room to the end framing of the mill. In the weighing-room a 30-foot length of the belt is supported by a Blake-Denison weighing-machine, and the weight of the "fines" passing into the mill is automatically registered. Within the mill the conveyor is fitted with an automatic travelling tripper, with double discharge, arranged to run above the ore-bins over a track, 164 feet in length, carried on brackets bolted to the belt-stringers of the conveyor staging. This belt, 20 inches in width and 220 feet in length between pulley-centres, runs at a speed of 400 feet per minute and has a carrying-capacity of 168 tons per hour. A $1\frac{1}{2}$ -inch hose-pipe is clamped to the tripper, its nozzle being directed so that a stream of water plays on the upper surface of the belt just after it has

passed round the head pulley of the tripper. The hose-pipe, carried on rollers fixed to uprights bolted to the bin-caps, travels backwards and forwards with the tripper, and, as the tripper travels along towards the engine-room end of the mill, descends by its own weight over a pulley erected at the end of the mill and coils round a large cone provided for that purpose on the lower floor, to be unwound again as the tripper reverses and travels in the opposite direction. The hose-pipe is coupled to a 3-inch branch-pipe running below the lower floor of the mill from the 5-inch main water service-pipe to the crusher-station, supplied by the high-level return-water supply-tank. A collecting-box, fitted to the tripper, catches the washings from the belt and delivers them to a launder fixed to the posts of the conveyor staging, whence they are discharged by vertical box launders to a second launder, which, after running through the upper part of the bin, supported by hangers from the bin-caps, passes through the end lagging of the bin and the end framing of the mill and then turns to the east side of the mill and delivers the washings to the two settling-tanks previously referred to under the crusher-station. The overflow from these tanks is taken by a launder to a spitzkasten, situated between the corner of the mill and the tailings-wheel, and after the required degree of concentration has been obtained, by means of an adjustable baffle and a discharge-valve, the overflow from the spitzkasten is led to the return-water collecting-tanks outside the extractor-house, and the discharge is run directly into the main launder from the mill to the tailings-wheel. Arrangements have also been made enabling the washings, from both the crusher-station and the mill, to be by-passed directly to this spitzkasten without being first settled in the settling-tanks. The deposits in the settling-tanks are fed, from time to time as required, through doors in the bottom of the tanks, on to the No. 1 "fines"-belt (conveyor E) and returned to the mill ore-bins. The mill ore-bins measure, inside the lagging, 162 feet 3 inches in length by 24 feet $1\frac{1}{4}$ inch in width, with an average depth of 16 feet from the under-side of the bin-caps. They are divided into two compartments by a longitudinal partition of 3-inch by 9-inch deals, supported on each side at intervals of about 6 feet by posts 6 inches by 9 inches, and have a maximum storage-capacity of about 3,200 tons, or rather more than $2\frac{1}{2}$ days' supply for the stamps.

Owing to the spacing of the belt-drives, the stamps have been arranged differently on the two sides of the mill, being divided on the east side into five batteries of twenty heads each, and on the

west side into four batteries of twenty heads each, with two end batteries of ten heads each. The twenty-stamp batteries have centre king-posts 24 inches by 24 inches in cross-section, and intermediate and end king-posts 15 inches by 24 inches, whilst the ten-stamp batteries have centre and end king-posts 15 inches by 24 inches. There is 5 feet 9 inches clear space between the end king-posts of adjacent batteries, and 15 feet 9½ inches between the end framing of the mill next the engine-room and the end king-posts of the first batteries. The end king-post of the ten-stamp battery, at the amalgamating-room end of the mill, is a 24-inch by 24-inch post. This has been put in to permit of the addition, at some future date, of another ten stamps, making this end battery into a twenty-stamp one similar to the other twenty-stamp batteries. There is also space at the amalgamating-room end of the mill, on the east side, for a ten-stamp battery similar to that on the west side next to the engine-room, thus bringing the total number of stamps in the mill up to 220, and enabling a minimum of 200 stamps to be in constant use. The mill main-line shafting, ranging in diameter from 10 inches in the engine-room to 5 inches in the amalgamating-room, runs down the centre of the mill, supported by ring-oiling bearings provided with means for both vertical and lateral adjustment, and bolted to sole-plates checked into and bolted to the strake-sills. The belt-pulleys, of cast-iron, 46 inches in diameter by 17 inches in width of face, run loose on the line shafting, and are fitted with Seymour friction-clutches keyed to the shaft, and designed to transmit 50 HP. when running at 70 revolutions per minute; these clutches are operated by hand-wheels mounted on standards on a platform carried by joists housed into and screwed to the main struts under the bins. Both pulleys and clutches are in halves, for convenience in erection and repairs. The cam-shaft pulleys, 70 inches in diameter by 17 inches in width of face, built up of clear pine boards spiked and glued together, are driven by seven-ply red rubber belting, 16 inches in width, manufactured by the Manhattan Rubber Company, and are arranged with as flat a drive as possible, in order to do away with the necessity of belt-tightening gear. The cam-shafts run at 46 revolutions per minute, giving 92 drops per head per minute, and have each ten Blanton cams fitted to the shaft in such positions as to cause the heads to drop in the following order—3, 8, 5, 10, 1, 6, 4, 9, 2, 7, counting from the pulley end of the shaft. The stems of the stamps are 16 feet in length by 3½ inches in diameter, the heads are 24 inches by 9 inches, the shoes 12 inches by 9 inches, the dies 6 inches by 9 inches, and the tappets 13 inches by 9 inches, arranged and fixed in position for

a 7-inch drop. The weights are—stem, 592 lbs.; head, 380 lbs.; shoe, 237 lbs., and tappet, 147 lbs.; giving a total falling weight of 1,356 lbs., or, if 14-inch shoes are used, 1,400 lbs. The falling weight of the stamps, the height of drop, and the number of falls per minute, have all been calculated with the object of giving the stamps a minimum output of 5.5 tons of ore per head per 24 hours, crushed through wire screening of 1,000 meshes to the square inch, or a total output for the mill of 1,100 tons per day of 24 hours. The mortar-boxes, with the exception of two which are of the Morrison open-front type, are all of the Homestake pattern, weighing approximately 5 tons each, and stand on $\frac{1}{4}$ -inch rubber sheeting on the top of piles to which they are securely bolted down. The piles are built up of eight pitch-pine blocks 15 inches by 15 inches by 12 feet 9 inches in length, carefully dressed on the joint faces, and accurately cut to receive a key 8 inches square in cross-section, gauged to width and thickness, and driven in after the blocks have been firmly bolted together. They rest, at the bottom of the pile-pits, on a solid foundation of concrete, and are grouted in with concrete to the level of the underside of the mud-sills. The boxes are lined with manganese-steel plates bolted to the casting, have false bottoms $2\frac{1}{2}$ inches in thickness, and are fitted on top with cover-boards $1\frac{1}{2}$ inch in thickness, and in front with screen-frames covered with wire-screening of 1,000 meshes to the square inch. Each box also has a metal lip bolted to it at the back to act as a shoot, and to receive the ore delivered to the box by the ore-feeder. Behind each box the mill ore-bin is fitted with a regulating sliding-door and a shoot, delivering the ore from the bin to the hopper of the feeder. This shoot is divided into two parts, a stationary upper part bolted to the bin-door trimmers, and a lower movable part bolted to the feeder-hopper and free to move with it. The ore-feeders are of Messrs. Fraser and Chalmers' "Suspended Challenge" type, and are hung from rails, supported, in front by brackets bolted to a 6-inch by 6-inch trimmer between the knee-beams, and at the back by brackets bolted to the front of the main lower stringers. The feed-motion is obtained by a buffer-lever operated by a tappet fixed below the bottom guide-blocks on the centre stem of each five heads of stamps.

The water-service to the batteries is designed to give to each mortar-box a maximum of 10 tons of water per ton of ore stamped, and is supplied by the 11-inch main from the low-level return-water tanks, a 9-inch branch from the main running to the mill, where, after passing through the west side-wall framing, it is carried across the mill under the lower floor at the engine-room end, and gives off

two 8-inch branches running the full length of the mill, one below each table floor, and diminishing as they approach the amalgamating-room to 6-inches in diameter. Each branch-line is tapped for stand-pipes, three to serve each battery of twenty stamps: one $3\frac{1}{2}$ inches in diameter, secured to the centre king-post, and giving off two horizontal $2\frac{1}{4}$ -inch branches running above and in front of each centre-box; and two $2\frac{1}{4}$ inches in diameter, one secured to each outer king-post, turning at right-angles to run above and in front of each outer box. From these horizontal pipes two $1\frac{1}{2}$ -inch branches are taken and led through the cover-board of each box. Each $2\frac{1}{4}$ -inch and $1\frac{1}{2}$ -inch branch, as well as each stand-pipe, is provided with a wheel-valve, and in addition a bibcock, with a length of hose attached for washing-down purposes, is fitted to each stand-pipe below its wheel-valve. The water-service to the ten-stamp batteries is identical with that to the two centre boxes of the twenty-stamp batteries.

The 3-inch branch from the main running from the high-level return-water supply-tank, already referred to as giving off a $1\frac{1}{2}$ -inch branch to the tripper working with conveyor F, supplies the mill fire-service, branching into two $2\frac{1}{4}$ -inch pipes, one under each side platform, supplying two $1\frac{1}{2}$ -inch stand-pipes on each side of the mill. These stand-pipes are clamped to the studs of the side-wall framing, and are provided with distributing hose and nozzles.

The tables, forty in number, one to each mortar-box, are firmly bolted down to the table floors; are covered with amalgamated copper plates 14 feet $10\frac{1}{2}$ inches in length, 4 feet 11 inches in width, and $\frac{1}{8}$ inch in thickness; and have a fall of 1 in 12 to transverse launders at the bottom of the tables. The crushed ore, passing through the wire screens in front of the mortar-boxes, falls upon the copper plates and runs over them in an even stream, to be caught by the transverse launders above-mentioned, and led by short launders with a fall of 1 in 12 to the mercury traps. These traps are of cast-iron in one piece, with a circumferential launder provided with a discharge-lip round the upper edge, and with an opening at the bottom, fitted with a screw-plug. Any free mercury passing over the plates, collects, owing to its greater specific gravity, at the bottom of the traps, and is drawn off from time to time as required through the openings mentioned above, whilst the sands and water flowing over the upper edge are caught by the circumferential launders, and carried by short launders with a fall of 1 in 12 to the two 12-inch by 9-inch main launders. Each table-floor has a fall of 1 in 12 to a launder, provided for the purpose of washing the washings when the floor is cleaned down, running

below the whole length of the free edge of the floor, which discharges the washings into short branch-launderers running with a fall of 1 in 12 to the two main launderers. These launderers have a fall of 3·5 per cent. and run, outside the mill, one on each side, the full length of the building, the one on the east side having to turn at right-angles on reaching the end of the mill, and pass below the floor of the amalgamating-room in order to unite, at the south-west corner of the mill, with the launder running down the west side of the building, and form the 18-inch by 9-inch main launder carrying the tailings to the tailings-wheel. These launderers are fitted with a false bottom of pitch-pine, 1 inch in thickness, pierced with $1\frac{1}{2}$ -inch circular holes, spaced zig-zag at intervals of 2 feet, provided for the purpose of catching any mercury that may have escaped the mercury-traps. Two 5-ton cranes are provided in the mill, one on each side, below the middle roof; they are carried on runners extending along the full length of the mill, supported by brackets bolted on the inner side to the upper bin-posts, and on the outer side to the studs of the side-wall framing over the storey-posts. These cranes have a clear lift from the lower platform at each end of the mill through four trap-doors, fitted, two on each side of the mill, in the cam-shaft platforms. Two-ton crawls have also been erected, one on each side of the mill, for handling the battery fittings; they run the full length of the building on the bottom flanges of a rolled-steel beam of I-section bolted to the under-side of the tie-beams of the middle roof trusses.

The amalgamating-house, built on to the south end of the mill, is divided into a Battery Manager's office, 13 feet $7\frac{1}{2}$ inches by 11 feet 1 inch, a store 10 feet by 11 feet 1 inch, and a clean-up room 36 feet by 24 feet, all inside measurements. The fittings of the clean-up room consist of an amalgam-press, two 36-inch ball-mills, a 30-inch grinding-pan, a screen washing-box, sink, etc. Each ball-mill discharges on to a table 2 feet 3 inches by 6 feet, covered with a copper plate, $\frac{1}{8}$ inch in thickness, sloping down to an end launder, which carries the discharge from the ball-mill to a small settling-tank provided with a vertical box-launder leading the waste-overflow to a gutter running down the centre of the clean-up room, any free mercury escaping from the ball-mills being caught by a small mercury-trap fitted to the launder at the bottom of each table. The discharge from the grinding-pan is taken by a $1\frac{1}{4}$ -inch pipe to a settling-tank 2 feet in width by 6 feet in length. The ball-mills and grinding-pan are driven by belts from a countershaft carried on the tie-beams of the roof-trusses and actuated, through a quarter-turn belt-drive, by a pulley keyed on the tail end of the mill main-line

shafting. A settling-tank, 10 feet by 3 feet, has been erected outside the west end of the clean-up room and receives the overflow from the screen washing-box, the sink, and the grinding-pan settling-tank, which is brought to it by a 4-inch by 3-inch launder running along outside the building, as well as the washings from the floor of the clean-up room and the overflow from the two settling-tanks in connection with the ball-mill tables, which are led to it by a central gutter in the granolithic flooring of the clean-up room. The overflow from this tank is carried by a 6-inch by 3-inch launder direct to the main launder leading to the tailings-wheel. The water-service to the clean-up room is taken from the battery water-service mains, and after giving off 1-inch branches to the screen washing-box, the sink and the grinding-pan, ends as a 1-inch standpipe fitted with a hose for washing down the clean-up room.

Tailings-Wheel.—The tailings-wheel, 72 feet in diameter and of the double bucket-type, has been designed, when running at $3\frac{1}{2}$ revolutions per minute, to lift through a vertical height of 61 feet a maximum weight of 14,100 tons per 24 hours, made up of 12,100 tons of tailings from the mill and 2,000 tons of concentrates discharged by the spitzkasten treating the washings from the crusher-station and mill, and the slimes from the sands-treatment tanks. The rim of the wheel is built up of a channel, 10 inches by 4 inches by $\frac{1}{2}$ inch, a $\frac{1}{2}$ -inch steel cover-plate, and four $\frac{1}{4}$ -inch steel side-plates, the inner side-plates being riveted to the flanges of the channel, and the outer side-plates to two angle-bars, 2 inches by 2 inches by $\frac{3}{8}$ inch, riveted to the edges of the cover-plate. Two angle-bars, 4 inches by 4 inches by $\frac{1}{2}$ inch, spaced 4 inches apart, are riveted to the outside of the rim, the rivets passing through the cover-plate and centre channel and binding all together, and have fitted between them, and securely bolted in place, a bed of hardwood blocks grooved to retain the driving-rope, whilst the rim is further strengthened by transverse bolts and angle stiffening-brackets. There are 225 buckets on each side of the wheel, built up of a wood casing fitted between the outer and inner side-plates and secured by screws to the side- and cover-plates, and of 1-inch boards screwed to bevelled cleats secured by screws to the back and sides of the wooden casing, which form the bottoms of the buckets and are set tangentially to a bucket pitch-circle of 60 feet diameter. The rim is supported by one hundred and twelve 1-inch direct spokes, fifty-six on each side, fitted at each end with lock-nuts and washers and threaded through holes so drilled in the outer flanges of the cast-iron hubs as to give them a straight lead to the holes drilled in the rim, through the web of the 10-inch by 4-inch channel-bar, the cover-

plate, and the 4-inch by 4-inch angle-bars outside the rim, thus rendering it possible to subject them to the maximum tension which their section warrants. The wheel is carried by two A-frames built up of light steel bars of channel and "I" sections, and strengthened with diagonal and cross bracing of channel- and tee-bars, the inside centre leg of each A-frame, a 14-inch by 6-inch I-beam, directly supporting the ring-oiling bearings on which the shaft runs. Struts, riveted to the outer legs of the A-frames and stiffened by diagonal and cross bracing, support four 10-inch by 3-inch channel-bars sloping with a fall of 3 per cent. to the spitzluten-framing, and carrying the launder-platforms around the wheel and across to the sands-treatment tanks. Drip-aprons are provided for each set of buckets, below the launder-platform, and are hung from frames riveted to the launder-platform channels and supported by stays from the A-frames. The tailings-wheel is driven from the end of the mill line-shafting by a rope-drive and spur-gearing placed between the south end of the mill and the amalgamating-room. The 1½-inch driving-rope, of hemp-covered steel wire, makes a half-lap round a 12-foot tension-pulley, fitted to a carriage having a horizontal travel of 15 feet and provided with adjustable balance-weights enabling any required degree of tension to be given to the rope, and then makes two half-laps round a 12-foot cast-iron grooved driving-pulley before passing to the tailings-wheel, where it lies in the wooden groove on the rim previously described.

The main launder, conveying the tailings from the mill, the discharge from the spitzkasten treating the overflow from the crusher-station and mill settling-tanks, and the discharge from the spitzkasten dealing with the slimes flowing from the sands and concentrates treatment-tanks, runs with a fall of 3·5 per cent. up to the rim of the wheel, where it divides into two branches, which run, at the same fall, on either side of the rim, and, on reaching the centre-line of the wheel, make a double right-angle turn, first inwards and then towards the mill, in order that the tailings may enter the buckets moving in the same direction as the wheel itself. The buckets discharge on to aprons designed to lead the tailings without splashing into two 18-inch by 12-inch launders carried—one on each side of the wheel—on the launder-platform, and running with a fall of 3 per cent. to unite and form the single 18-inch by 12-inch launder leading to the spitzluten. The buckets are designed to discharge their entire contents into these launders, but provision has been made, nevertheless, for dealing with any overflow from the buckets or wheel, in the first place by fitting the drip-aprons as previously mentioned to catch any tailings spilt from the buckets or carried beyond the launders,

and lead them back again to the wheel ; and, in the second place, by providing a sump in the wheel-race where any tailings which may in spite of precautions fall from the wheel, collect and are fed from time to time as required back again into the wheel.

Spitzluten, Spitzkasten, etc.—Between the tailings-wheel and the east end of the sands treatment-tanks (Figs. 4, Plate 4) is situated a wooden trestling carrying the spitzluten, the spitzkasten, and the water-tanks supplying the former ; and also supporting the lower end of the launder-platform of the tailings-wheel, as previously mentioned, and the east ends of the upper, middle, and lower platforms which run the whole length of the sands-tanks. Just in front of the spitzluten is situated the first sampler, the 18-inch by 12-inch launder from the tailings-wheel widening to 24 inches before reaching the sampler and to 33 inches by 9 inches for a short distance after leaving it, soon dividing however into two 18-inch by 9-inch branches, one running to each set of spitzluten. The samples taken by the first sampler are discharged into a launder leading to a sample-box standing on the spitzluten platform.

The spitzluten, eight in number, are arranged in two sets of four, each spitzlute being fitted with an adjustable baffle and with a discharge-nozzle having a $\frac{3}{8}$ -inch opening, and are supplied with water by a 2 $\frac{1}{2}$ -inch pipe from the supply-tanks above, the first spitzlute of each set being also fitted with a wire screen of $\frac{1}{4}$ inch mesh for removing any particles from the tailings which might otherwise get into and block the discharge-nozzles. The spitzluten water-supply tanks, four in number, of 400 gallons capacity each, are carried on a platform supported by trestles bolted to the spitzluten platform, and are automatically kept filled to a constant level by a ball-valve fitted to a 5-inch supply-main from the high-level return-water supply-tank, thus ensuring a constant supply of water at a uniform pressure to the spitzluten. The overflow from each spitzlute passes directly into the next spitzlute, and the overflow from the end spitzlute of each set passes directly to one of the two spitzkasten. Each spitzkasten is fitted with a fixed baffle, has an end overflow-launder common to the two launders conveying the overflow or "slimes" to a 6-inch by 6-inch vertical launder discharging into the branch-launder carrying the slimes from the two top concentrates-tanks to the main slimes-launder running to the slimes-plant, and has in addition a 7-inch discharge-pipe fitted with a valve for regulating the amount flowing away as "sands."

The discharge from the spitzkasten runs into two 14-inch by 9-inch launders, which soon unite to form one launder, 24 inches by 9 inches in section, running to the second sampler. The samples taken here

are deposited in a sample-box placed on the upper platform of the sands-tanks, and to ensure that they shall give a true sample of the sands the bottom of the launder running to the sampler is fitted with diamond-shaped wood blocks for the purpose of thoroughly mixing the sands. The cross-section of the launder where it leaves the sampler is 33 inches by 9 inches, but contracts almost immediately to 14 inches by 9 inches and runs with a fall of 4 per cent. along the whole length of the sands-tanks carried on the upper platform. The discharge from the spitzluten can be given any required degree of concentration by adjusting the baffles and the water-supply, but it usually amounts to about 10 per cent. of the total mill pulp when crushed through screens of 1,000 meshes to the square inch. The concentrates are discharged through the nozzles before mentioned and fall into two 8-inch by 7-inch concentrates-launder, fitted with mercury-traps placed immediately under the nozzles, carried upon a platform below the spitzluten platform and running with a fall of 4 per cent. until they pass the last spitzlute; thence, bending down at an angle of 35° , they unite and pass as a 24-inch by 7-inch launder, fitted as in the case of the sands-launder just described with diamond-shaped wood blocks, with the same fall to the third sampler. The concentrates samples are deposited in a sample-box, which, together with the third sampler, stands on a short intermediate platform situated between the upper and middle platforms. Starting below the sampler, with a width of 27 inches and a depth of 7 inches, the launder soon contracts to 8 inches by 7 inches and runs with a fall of 4 per cent. carried by a short platform immediately below the upper platform, until directly over the centre-line of the first two tanks, where, branching right and left, it runs at the same fall to above the centre of each tank and delivers the concentrates to the distributor of either the No. 1 or the No. 2 top tank. The three samplers are of the swing-arm type, automatically operated by a balance-weight and cataract, the number of samples taken per hour being regulated by adjusting the quantity of water delivered to the hoppers of the cataracts by a $\frac{3}{4}$ -inch pipe coupled up to the tanks supplying the spitzluten.

Sands and Concentrates Treatment Plant.—The general arrangement of the sands and concentrates treatment-plant is shown in Figs. 1 and 4, Plate 4. It will be seen that there are ten sets of double-treatment superimposed tanks, arranged in two rows of five tanks each, placed 58 feet apart, with provision at the west end for future extension if necessary, the individual tanks being spaced 54 feet apart, centre to centre, and successively stepped down 9 inches, giving a total drop of 3 feet between the first and last sets of tanks.

The first two sets of tanks are reserved for the treatment of the concentrates separated by the spitzluten, whilst the remaining eight sets are used for the treatment of the sands discharged by the sands spitzkasten. Each tank rests on a decking of 3-inch by 9-inch deals, spaced 3 inches apart, carried by rolled steel joists of I-section laid on steel girders supported by cast-iron columns standing on capstones on a solid foundation of concrete. The bottom tanks are 50 feet in diameter and 8 feet in depth internally, are built up of $\frac{1}{8}$ -inch bottom and $\frac{1}{4}$ -inch side-plates of steel, lap-jointed and single-riveted, and connected together by a 3-inch by 3-inch by $\frac{3}{8}$ -inch angle-bar riveted round the outside of the tank, a stiffening angle-bar rim, 3 inches by 3 inches by $\frac{3}{8}$ inch, being also riveted round the upper edge, inside the tank. The top tanks are 50 feet in diameter and 7 feet in depth, built up in the same way but having in addition a 4-inch overflow-launders, formed of 4-inch by 3-inch by 3-inch by $\frac{1}{4}$ -inch Z-bar and $\frac{1}{4}$ -inch plate riveted round the top of the tank. The outer edge of this launder is 3 inches above the top of the tank, and the bottom slopes from both sides of a point on the inner side of the tank, 6 inches below the edge of the launder, to a discharge-lip on the opposite side, 14 inches below the edge of the launder. These launders are no longer in use, as it was found that the tanks were too large to permit of the slimes being efficiently separated by this means, and slat-doors have now been substituted, four doors being spaced at equal distances around the circumference of each top tank. These doors have an opening, 2 feet in width, covered with a wire screen of 1-inch mesh and provided with a canvas roller-blind secured to the bottom of the tank, which is unrolled in front of the wire-screen as the tank fills, thus retaining the sands but permitting the slimes to flow away over the top of the roller-blind and be discharged from the tank by 6-inch pipes fitted to the side of the tank opposite each door. Each top tank is provided with a Butters distributor, automatically delivering the concentrates or sands to the tanks, consisting of a steel hopper revolving freely on a bearing fitted to the upper end of a steel tube 4 inches in diameter secured to a foot-plate bolted in the centre of the tank to the bottom plates, and stayed at the top by four $\frac{3}{4}$ -inch tie-rods bolted to the side-plates of the tank. The hopper is covered in by a wire screen of $\frac{1}{4}$ -inch mesh, and is fitted with fourteen $2\frac{1}{4}$ -inch distributing-pipes of graduated length, screwed into the circumference of the hopper and supported where necessary by tension-rods from its edge. Each tank is provided with twelve discharge-doors, 18 inches in diameter, hinged at one side so that, when opened, they can

swing back and be held up out of the way by a steel clip fixed to the bottom of the tank, and constructed of pressed steel of so light a section that they can be easily operated by one man. Immediately below each discharge-door of the lower tanks a steel hopper, fitted with a hinged flap giving ready access to the discharge-door, is bolted to the lower flanges of the steel joists, and has riveted to its lower edge a steel shoot, designed to discharge the "residue-sands" directly on to one of the belts of conveyors L1 and L2, which run in trenches below each row of tanks and receive the "residue-sands" from the lower tanks, to discharge them at right-angles on to conveyor K1, the second section of the main waste conveyor to the dump. Each belt is 18 inches in width and 285 feet 6 inches in length between pulley-centres, and, driven by a 15 HP. motor at a speed of 500 feet per minute, has a carrying-capacity of 170 tons per hour. Each tank is provided with a false bottom of 3-inch by $1\frac{1}{2}$ -inch joists placed on edge, 12 inches apart, with $1\frac{1}{2}$ -inch square laths $1\frac{1}{2}$ inch apart running at right-angles to them and spiked to their upper edges; whilst to ensure free drainage 6-inch by $1\frac{1}{2}$ -inch by $\frac{3}{4}$ -inch strips are nailed at intervals of 6 inches to the bottom edges of the joists. A board, 1 inch in thickness, bent to the curve of the tank, is spiked to the ends of the joists, a space 1 inch in width being left between it and the tank. The filter-cloths, consisting of a lower layer of fine jute cloth resting on the laths, and an upper layer of coarse coconut-matting, are carefully fitted round the openings to the discharge-doors in the top and bottom tanks and also round the columns standing in the lower tanks, and are then tacked down round these openings and round the circumference of the tanks, and the outer edges of the cloths well rammed down in the space between the curved boards just mentioned and the sides of the tanks.

Three platforms run the full length of the tanks from the spitzluten trestling at the east end to the last set of tanks at the west end, and are known respectively as the upper, middle, and lower platforms. The upper platform, supported by trestles whose sills rest on the upper flanges of the inner girders sustaining the top tanks, starts below the spitzluten platform, where it carries the first part of the concentrates flume, and then, stepped up 9 inches, runs horizontally below the spitzkasten platform and out above the concentrates-tanks, until it meets the main sands-laundry, when it inclines downwards and proceeds with a fall of 4 per cent. to just beyond the last sands-tanks; the middle platform runs between the top tanks, with a fall of 1 in 72 corresponding to the drop of the tanks, being carried on rails spiked to the posts of the trestles carrying the upper platform, and on short trestles standing on the

upper flanges of the inner girders supporting the top tanks; whilst the lower platform runs, with a fall of 1 in 72, between the bottom tanks, and is supported by short trestles resting on the top flanges of the inner girders carrying the bottom tanks. Short flights of steps lead from the middle and lower platforms to each tank in the top and bottom row respectively, and stairs are provided at each end of the tanks, between the various platforms, and from the ground to the lower platform. At the east end of the tanks, between the upper and middle platforms, there is a short intermediate platform extending to just beyond the centre of the concentrates-tanks and carrying the concentrates-sampler and sample-box and the lower section of the concentrates-launders.

The main sands-launders, 14 inches by 9 inches, runs with a fall of 4 per cent. from the sampler below the sands-spitzkasten to above the last sands-tanks, being carried above the horizontal portion of the upper platform on short trestles, and resting directly on the decking of the inclined part. From the sides of the main launder, above each pair of sands-tanks, 14-inch by 9-inch launders branch off, pass at an angle of 45° through the upper platform, and continue as transverse launders running with a fall of 4 per cent. across each tank to deliver the sands by short 7-inch by 7-inch vertical box-launders to the hoppers of the distributors. The transverse launders are trussed and supported at each end, under the upper platform by bearers spiked to the legs of the platform trestles, and above the distributors by 3-inch by 4-inch tee-bar bridges which span the tank and are fixed in position by gusset-plates bolted to the sides of the tanks. The concentrates are delivered to the distributors of the two top concentrates-tanks, in an exactly similar manner, by the two 8-inch by 7-inch branch-launders into which the main concentrates-launders, carried by the intermediate platform, divides above the centre-line of the two tanks. From the discharge-lips of the circular overflow-launders 6-inch by 9-inch branch-launders are led at an angle of 45° round the top concentrates- and sands-tanks to discharge into the two 12-inch by 9-inch main branch slimes-launders running, one on each side of the tanks, with a fall of 1 per cent. from the west end of the cyanide-plant up to the spitzen-luten framing, where they discharge at right-angles into the 16-inch by 9-inch main slimes launder, proceeding with the same fall to the temporary settling-tanks. This launder system, as well as the slimes spitzenkasten and the platform leading to it, was only a temporary arrangement pending the design and erection of a complete slimes-treatment plant, and has now been replaced by a system of launders, consisting of six main branch-launders running south

with a gradient of 1 per cent., one at the east end of the plant receiving the overflow from the sands spitzkasten, one at the west end of the plant, and one between each pair of tanks, designed to collect the slimes discharged from the 6-inch pipes in connection with the slat-doors of the top set of tanks and deliver them to the main slimes-launders, which runs at a gradient of 1 per cent. along the south side of the sands-plant, up to the slimes settling-tanks (Figs. 6, Plate 5), supported by trestles from the ground and by bearers fitted between the steel joists under the top tanks and spiked to the underside of the 3-inch by 9-inch decking.

The water-service to the sands and concentrates treatment-tanks is supplied by the 11-inch main from the low-level return-water supply-tanks, a 6-inch branch from the main running underground to between tank No. 1 and tank No. 3 where, rising vertically upwards and bending inwards, supported by the girders carrying the top tanks, it passes below the middle platforms and gives off 6-inch branches to the right and left, running with a fall of 1 in 72 the whole length of the tanks, supported on the sills of the trestles carrying the upper and middle platforms. The main, fitted at the west end of the plant with a blank flange to permit of possible future extension, and at the east end with a screw-plug, gives off between each pair of tanks a 6-inch transverse branch supplying at each end a 6-inch branch to the top tank and a 4-inch branch to the bottom tank, and in addition supplies four 1-inch standpipes provided with bibcocks, unions, and hose-pipes for washing-down purposes, two for the middle platform and two for the lower platform. The cyanide solutions are brought to the tanks by three 4-inch pipes, for strong, medium, and weak solutions respectively, carried by short trestles along the east end of the extractor-house and then by trestles about 8 feet in height to between tanks Nos. 5 and 7, where, rising vertically upwards and bending inwards supported by the girders carrying the top tanks, they pass below the middle platform and give off 4-inch branches to the right and left running with a fall of 1 in 72 the whole length of the tanks, supported by the sills of the trestles carrying the middle and upper platforms. These 4-inch mains are fitted at the west end of the plant with tees and plugs, to permit of future extension if necessary, and between each pair of tanks with 4-inch connections giving off 4-inch branch-pipes running horizontally below the middle platform up to the tanks, where they rise vertically close to the sides of the tanks and supply, to the bottom tank, a 4-inch branch from each main, and to the top tank, a 4-inch branch from the strong and medium mains only. At the bottom of each tank there are con-

nections for two pairs of 2-inch drain-pipes, each pair uniting to form a 3-inch pipe, and these two 3-inch pipes again uniting to form the 3-inch main drain-pipe conveying the solutions from each tank to the distributor-box in the extractor-house. The 2-inch pipes run parallel to the joists under the tanks and are supported by wooden bearers laid on the bottom flanges of the joists, whilst the main 3-inch pipes from the top tanks run with a fall of 1 in 72 below the middle platform, and those from the bottom tanks with the same fall below the lower platform, each set of pipes being carried by wooden bearers resting on the bottom flanges of the inner girders supporting the tanks. At the west end of the plant the ten drain-pipes from the top tanks and the ten drain-pipes from the bottom tanks are suspended by hangers from the middle and lower platform-joists respectively, and thence run, supported on trestles and with a fall of 23 inches, to the extractor-house, where the top set of pipes bends downwards, through a vertical distance of 13 feet, and enters the extractor-house and passes to the distributor-box on the same level as the bottom set of pipes.

The sands discharged by the sands-spitzkasten pass over the sands-sampler and are carried by the main and branch sands-launders to the hoppers of the automatic distributors, to be evenly deposited in the top tanks, where the sands settle, whilst the slimes flowing away over the slat-doors are collected by the branch slimes-launders and carried by the main slimes-launders to the settling-tanks of the slimes-plant. The sands deposited in the top tanks, after treatment with cyanide solution, are discharged into the bottom tanks, and, having been subjected to a second treatment with cyanide solution, are shovelled as "residual sands" through the discharge-doors into hoppers, and are thence led by shoots to conveyors L1 and L2 below the tanks, by which they are fed on to conveyor K1, to be carried up to and discharged on the waste-dump. The concentrates pass through a similar treatment, whilst the gold-bearing solutions from both the top and bottom sands- and concentrates-tanks are carried by the 3-inch drain-pipes to the distributor-box in the extractor-house.

Lime Feeding-Plant.—In close connection with the sands and slimes treatment-plants is the lime feeding-plant, contained in a small building standing on the ground-level immediately to the south of the spitzluten framing. Lime ground by a ball-mill situated on the main floor of the building falls into a storage-bin, built below the main floor, and is conveyed by $\frac{5}{8}$ -inch feeder-chain running through the bin to the boot of an elevator, consisting of a 3-inch belt with 1-inch by 1-inch by $2\frac{7}{8}$ -inch wood slats nailed to it

at intervals of 6 inches, which, raising the lime through a vertical height of 23 feet, discharges it into the main branch slimes-launders at the east end of the sands treatment-tanks just before it receives the overflow from the sands spitzkasten. A $3\frac{1}{2}$ -HP. motor, situated on the main floor, actuates by means of a belt-drive a second-motion shaft from which three belts are taken off, driving the ball-mill, the head end of the elevator, and a third-motion shaft which by means of a belt-drive operates the feeder-chain. The ball-mill is fitted with a clutch, enabling it to be stopped or started without interfering with the constant running of the feeder-chain and elevator; whilst the feed of the chain can be adjusted, as required, by altering the position of the belt on the cone-pulleys, transmitting power from the second- to the third-motion shaft.

Slimes Treatment-Plant.—The general arrangement of the slimes treatment-plant is shown in Figs. 1, Plate 4, and Figs. 6, Plate 5. It will be seen that there are twelve tanks, arranged parallel to the sands-tanks in three groups of four tanks each, the group of four tanks at the west end being reserved for settling the slimes previously to treatment in the other eight tanks. The tanks are spaced, east to west, 54 feet apart centre to centre, on the same centre-lines as the tanks of the sands treatment-plant, and north to south, those of the two end groups are spaced 58 feet apart, centre to centre, and those of the centre group 54 feet apart centre to centre. The tanks are 50 feet in diameter, 12 feet in depth at the sides, and 16 feet in depth at the centre, all inside measurements; the conical bottoms are built up of $\frac{1}{4}$ -inch steel plates, with the exception of the centre-plate, which is $\frac{3}{16}$ -inch in thickness, and the sides are composed of $\frac{5}{16}$ -inch steel plates, all lap-jointed and single-riveted, with $\frac{5}{8}$ -inch rivets for the side-plates and $\frac{1}{2}$ -inch rivets for the bottom-plates, whilst the sides are connected to the bottoms of the tanks by $3\frac{1}{2}$ -inch by $3\frac{1}{2}$ -inch by $\frac{1}{2}$ -inch angle-bars riveted outside to the side and bottom plates. The four tanks at the west end of the plant have a 6-inch overflow-launders, formed of 6-inch by 3-inch by 3-inch by $\frac{3}{8}$ -inch Z-bar, and $\frac{1}{4}$ -inch plate, riveted round the top of the tank, the outer edge of this launder being 3 inches above the top of the tank, whilst the bottom slopes from both sides of a point on one side of the tank, 6 inches below the edge of the launder, to a discharge-lip on the opposite side of the tank, 18 inches below the edge of the launder. These four tanks have in addition an overflow-equalizer, of $4\frac{1}{2}$ -inch by 1-inch timber, securely bolted round the tops of the tanks on the inside, and afterwards planed absolutely level all round. The remaining eight tanks have no overflow-launder, but have, securely riveted round their upper edges on the inside, a $3\frac{1}{2}$ -inch by $3\frac{1}{2}$ -inch by

$\frac{1}{2}$ -inch stiffening angle-bar. Each tank has, erected inside it and bolted to angle-bar brackets riveted to the bottom plates, a steel trestle built up of $2\frac{1}{2}$ -inch by $2\frac{1}{2}$ -inch by $\frac{1}{2}$ -inch angle-bars, which supports the end of the branch-platform to the tank and serves as a guide and support to the centre pipe; and each tank is also provided with a 5-inch decanting-pipe bolted to the side of the tank and fitted with a stuffing-box and glands, enabling the free end of the pipe to be raised or lowered as required by means of a small winch bolted to the working deck. A main trench runs the full length of the plant from east to west and is joined by branch trenches, running from below the centre of each tank of the two end groups of four, as well as by a main branch-trench, into which converge branch trenches from below the centre of each of the four tanks of the centre group. This system of trenches is about 11 feet in depth below the ground-level, is paved with bricks on edge, and has, as well as the earth-beds on which the tanks directly rest, solid retaining-walls of coursed rubble-work. There are two main platforms, situated at right-angles to one another above the level of the top of the tanks, one 305 feet in length and 5 feet 8 inches in width, running with a fall of 1 per cent. from the east to the west end of the plant, and the other 83 feet in length and 3 feet 6 inches in width, running horizontally between the four tanks of the centre group to join the first platform a little to the east of its centre. These platforms, carried by timber trestles supported on and checked into hardwood posts firmly fixed in the ground, expand between each group of four tanks into spacious working-decks, supported on special trestles carrying 3-inch by 9-inch joists and 4-inch by 9-inch trimmers, to which the $1\frac{1}{2}$ -inch by 9-inch decking, spaced $1\frac{1}{2}$ inches apart, is secured, and are reached from the ground-level by three ladder-ways. Running at right-angles to these two main platforms are branch-platforms, to the centre of each tank, 28 feet in length and 3 feet in width, trussed and supported at their free ends by the steel trestles erected in the centre of each tank; whilst from the working-deck of the settling-tanks a branch-platform, 3 feet in width, runs horizontally for 36 feet, ending in two short flights of steps running down to the spitzkasten platform, which, supported by wooden trestling at a height of 13 feet 4 inches above ground-level, carries the slimes spitzkasten, the slimes sampler, and the end of the main slimes-launders from the sands treatment-tanks, and is approached by a ladder-way from the ground-level. The main slimes-launders discharge into two slimes spitzkasten designed to intercept, and discharge into a launder ceeding to the tailings-wheel, any sands which may have been led away with the slimes from the sands treatment-tanks.

The overflow from the spitzkasten is led by a 33-inch by 12-inch launder to a slimes sampler, similar in every respect to those previously described, and from there is conveyed to the slimes settling-tanks by a 33-inch by 12-inch launder, which divides into three 18-inch by 12-inch branches, one running to each of the first two settling-tanks and the third widening to 24 inches and dividing below the main platform, into two 18-inch by 12-inch branches passing one to each of the remaining two settling-tanks. The launders are carried below the platforms by bearers bolted to the platform-trestles, whilst the branch-launders are trussed and are supported at their free ends by bearers bolted to the steel trestles standing in the tanks. All the launders have a gradient of 1 per cent. and the branch-launders are fitted with settling-boxes designed for the purpose of thoroughly mixing the slimes with the lime, fed as previously described into the slimes-launder, and of so facilitating their settlement in the settling-tanks. Branch-launders, 18 inches by 9 inches, are bolted to the discharge-lips of the overflow-launders of the four settling-tanks, and converge at a gradient of 1 per cent. to a common 18-inch by 9-inch launder, running, at the same gradient, to the return-water collecting-tanks. The branch-launders are carried below the main platform by slings from the platform-joists, and the main launder by trestles up to the sands treatment-tanks, where it passes between the bottom tanks and the supporting columns, suspended by hangers from the lower platform of the sands treatment-tanks, and is then continued on trestling up to the return-water collecting-tanks. An 8-inch by 7½-inch launder receives the discharge from the slimes spitzkasten and runs with a fall of 3 per cent. carried on brackets bolted to the trestles conveying the main slimes-launder from the sands-plant to the slimes-plant, until it reaches the ground-level, where it is connected to a 4-inch pipe running below ground, at the same gradient, to deliver the separated sands to the main launder from the mill to the tailings-wheel.

Pump-House and Pumps.—Centrally situated between the three groups of tanks is the pump-house, containing:—two 8-inch centrifugal Morris slimes-pumps, each driven directly through a Voith coupling by the armature-shaft of a 35-HP. motor mounted on an extension of the pump bedplate; and two 5½-inch centrifugal pumps, mounted on a common bedplate and coupled directly by claw-clutch couplings to the armature-shaft of a 25-HP. motor placed between them. Three 10-inch main suction-pipes, one from each of the three groups of tanks, are coupled to the suction-flanges of the two Morris pumps, by a system of pipes and valves, in such a way that either both pumps may be used at the same time in connection with any

two of the three groups of tanks, or one pump may be pumping from any one of the three groups whilst the other pump is acting as a stand-by, or is being overhauled for repairs. Twelve 10-inch branches, four from each of the three main suction-pipes, run along the branch trenches below the tanks, to be bolted up to the $\frac{1}{8}$ -inch centre-plates of the conical bottoms, and are carried on 6-inch by 3-inch trestles along the main trench and on 13 $\frac{1}{2}$ -inch by 9-inch brick piers along the branch trenches, at a gradient of 2 per cent. from the tanks to the pumps. The pump deliveries are similarly connected to a system of 10-inch delivery-pipes, arranged to discharge either to waste or into any one of the eight treatment-tanks, the valve-system being such that either each pump can simultaneously be discharging the contents of two tanks, one from any two of the three groups, into two other tanks, one of each of the two treatment-groups, or to waste, or one pump can be standing idle whilst the other pump is at work. It will thus be seen that the pipe-system permits of the contents of any one of the twelve tanks being discharged by either pump, either into one of the eight treatment-tanks, or to waste; and also allows for either pump being used as a circulating-pump for any one of the eight treatment-tanks. The delivery-pipes are carried by wrought-iron slings, hung from the caps of the main platform-trestles, and have a gradient of 1 per cent. until they arrive above the pumps, where they bend down vertically and are bolted to the pump delivery-flanges.

The water-service main to the tanks, a 6-inch branch given off by the 9-inch main from the high-level return-water supply-tank, and the solution-main, a 6-inch pipe coupled up in series to the two slimes solution-pumps in the extractor-house, are both carried on trestling to below the main platform, where they each give off 6-inch branches running the full length of the tanks below the two main platforms, supported on bearers checked into and bolted to the main platform-trestles. These two mains give off between each pair of tanks 6-inch branches which, rising vertically and then bending at right-angles to rest on the main platform, are both coupled up to a 6-inch transverse branch running along and resting upon the decking of the branch-platforms. The transverse branches are fitted with a valve-system enabling either solution or water to be supplied to each tank, and with 6-inch hose-pipes and unions coupling their free ends to the 6-inch centre pipe supported and guided vertically through the centre of each tank by the steel trestles already referred to. Each centre-pipe acts as a valve to the 10-inch suction-pipe bolted to the bottom of the tank, having at its lower end a flange fitted with a rubber ring, and at its upper end a bridle clamped to the pipe

and terminating in a screw, operated by hand by means of a nut revolving in a wooden framing carried by the branch-platform joists, enabling the centre pipe to be either lifted off the machined upper surface of a valve-seat bolted inside to the bottom plate of the tank, permitting the slimes to flow to the pumps, or to be screwed down on to the valve-seat, shutting off the slimes from the pumps. The transverse branch between each pair of treatment-tanks gives off, in addition to the branch to each centre pipe, two 6-inch circulating pipes, one to each tank, inclined at an angle of 45 degrees to the centre-line of the main platform, in order that they may deliver water or solution tangentially to the circumference of the tank, and so set up a gyratory movement of the slimes in the tank, assisting in their thorough admixture with the solution. The eight 5-inch decanting-pipes, one in each of the eight treatment-tanks, are connected by 5-inch branch-pipes to a common 5-inch solution-drain running with a fall of 1 per cent carried on bearers bolted to the main platform-trestles, up to the east end of the slimes-plant, where it turns at right-angles and is carried by trestles to discharge into either of the two slimes filter-tanks. The four 5-inch decanting-pipes, one in each of the four settling-tanks, are connected by 5-inch branch-pipes to the main 5-inch water-drain proceeding at a fall of about 6 per cent. supported on bearers bolted to the trestles of the main platform, to be coupled up to the suction-flanges of the two 5½-inch centrifugal pumps in the pump-house. These pumps deliver the water decanted from the slimes in the settling-tanks, and also any water draining into the sump in the pump-house floor, by a 5-inch discharge-pipe carried on trestles, into the main 18-inch by 9-inch overflow-launders running as previously described from the settling-tanks up to the return-water collecting-tanks.

The slimes flowing from the slimes spitzkasten are carried by the main and branch launders to one of the settling-tanks, where, after falling into the settling-box and being intimately mixed by a system of baffles with the lime previously fed into the main slimes-launders running from the sands treatment-tanks, they quickly settle; whilst the clear water, flowing away evenly over the overflow equalizer bolted to the edge of the tank, is caught by the circumferential launder and led away by the overflow-launders to the return-water collecting-tanks for use over again in the mill and cyanide-works. After about 200 tons of slimes have settled, the overflow from the spitzkasten is turned into another tank, whilst the clear water still remaining in the tank is discharged by the decanting-pipe to the 5½-inch centrifugal pumps in the pump-house, and is pumped up to the launders running to the return-

water collecting-tanks. Solution is then pumped down the centre pipe, and, the pipe being raised by the screw-gear previously described, the settled slimes mixed with solution are allowed to flow to the 8-inch Morris pumps, by which they are discharged into one of the treatment-tanks, where, after being thoroughly mixed with solution through the agency of the circulating-pipe, they are again allowed to settle, and the clear solution is then drawn off by the decanting-pipe and discharged by gravity to either of the slimes filter-tanks. This treatment is repeated in a second and, if necessary, in a third tank, the slimes being finally washed down to the pumps with water and discharged to waste.

Extractor-Plant.—The general arrangement of the extractor-plant is shown in Figs. 1, Plate 4, and Figs. 7, Plate 5. The plant comprises the extractor-house, 120 feet by 50 feet, a clean-up room, 69 feet 6 inches by 50 feet, and a pump-room, 70 feet by 50 feet, all inside measurements; whilst outside the buildings are situated the tanks provided for preparing and storing the cyanide solutions, ready for pumping to the sands and concentrates treatment-plant and to the slimes-plant. The extractor-house contains the distributor-box and the filter-vats for distributing and filtering the solutions draining from the sands and concentrates treatment-tanks, and the extractor-boxes for the treatment of these solutions and the solutions draining from the slimes treatment-tanks. The cyanide manager's office and a laboratory are also included in the extractor-house building. The 3-inch drain-pipes, from the top and bottom sands and concentrates treatment-tanks, on entering the extractor-house, are each fitted with a plug-cock and with a union for connecting to a short length of hose-pipe, enabling the solution from any one of the drain-pipes to be led into any one of the four compartments of the distributor-box. These compartments are for waste and for weak, medium, and strong solutions respectively. The waste or the residual water retained by the sands and concentrates after they have settled in the top treatment-tanks, is forced out as the cyanide solution percolates through the settled sands and concentrates, and is led from its compartment of the distributor-box, either directly to the waste extractor-box for treatment on the possibility of its containing any gold-bearing solution, or to join the overflow from the slimes extractor-boxes carried by a 6-inch pipe to the slimes-filter or solution-tanks. The other three compartments of the distributor-box are each fitted with a 5-inch pipe leading the solutions directly to three filter-vats, 6 feet in diameter by 6 feet in height, each vat fitted with two filters consisting of vertical sliding frames, covered, the one nearest the inlet-pipe with an inner sheet of fine jute-cloth and an

outer sheet of coarse cocoanut-matting, and the one nearest the outlet-pipe with a single layer of the cocoanut-matting. The filtered solution is taken from the three vats by three 5-inch pipes, each supplying a 3-inch branch to three extractor-boxes. There are eleven of these boxes provided for the treatment of the solutions draining from the sands and concentrates treatment-tanks, three for strong solution, three each for medium and weak solution, a spare box for medium or weak solution as required, and one for waste. Each box is divided into a number of cells, fitted with zinc trays formed of $\frac{1}{8}$ -inch mesh iron-wire sieve and with covers of $\frac{1}{8}$ -inch mesh iron-wire sieve, and separated from each other by double baffle-boards spaced 3 inches apart, the first board of each pair extending from the bottom of the box to within 3 inches of the top, whilst the other baffle-board reaches from the top of the box to within 3 inches of the bottom. The overflow from the waste-box is taken directly by a 3-inch pipe to a waste-drain outside the building, whilst the 3-inch overflow-pipes from the strong, medium, and weak solution boxes unite to form three 5-inch mains carrying the overflow respectively to the strong, medium and weak solution tanks of the sands and concentrates treatment-plant. The solution decanted from the slimes treatment-tanks runs by gravity through a 6-inch pipe, to be discharged into one or other of the two slimes filter-tanks standing outside the extractor-house. These tanks are 40 feet in diameter by 10 feet in depth, are built of $\frac{1}{4}$ -inch steel side- and bottom-plates lap-jointed and single-riveted, with a 3-inch by 3-inch by $\frac{3}{8}$ -inch angle-bar riveted round outside the tanks to both the side and the bottom plates, a stiffening angle-bar of the same size riveted round inside the edge of the tank, and a stiffening channel-bar, 4 inches by 2 inches by $\frac{3}{8}$ inch, riveted round outside the tank about half-way down the side; and contain filter-beds about 5 feet in depth, built up of layers of graded stones with a top layer of sand. A 6-inch pipe carries the solutions draining through these filter-beds to the pump-room, where it is bolted to the suction of two 5 $\frac{1}{2}$ -inch centrifugal pumps, mounted on a common bedplate and coupled directly by claw-clutch couplings to the armature-shaft of a 25-HP. motor placed between them, which raise the solutions to a steady-head tank, 18 feet in diameter by 10 feet in depth, situated outside the east end of the extractor-house and fitted with a 6-inch main running to the extractor-house and giving off 3-inch branches to each of the four slimes extractor-boxes, and with an overflow-pipe returned to the filter-tanks. The extractor-boxes for the solutions from the slimes-plant are in every respect similar to those in use for the solutions draining from the sands treatment-tanks and are provided with 3-inch overflow-pipes uniting to form a 6-inch main, which,

after being joined by the 4-inch pipe from the waste-compartment of the distributor-box, runs to discharge either into the slimes filter-tanks or into the slimes solution-tanks. These solution-tanks, two in number and 40 feet in diameter by 10 feet in depth, are of steel plate, built up and strengthened similarly to the filter-tanks, and are situated outside the extractor-house, alongside the latter. The clean-up room contains the acid-tank, washing-tank, filter-press, two ball-mills, and a zinc-lathe of the Betty type with a 25-HP. motor for driving one of the ball-mills, the lathe, and the pump of the filter-press; whilst there are also two drying-furnaces, a reverberatory and a tilting-furnace, two smelting-furnaces, and a slag-washing tank, together with cyanide, zinc, and cut zinc stores fitted up within the building. The acid tank, 7 feet 9 inches in diameter by 5 feet 8 inches in height, is provided with a hardwood agitator worked by hand and with a movable iron hood, fitted with a vent-pipe passing through the roof of the building, for carrying off the acid fumes generated when the tank is in use. Steam is led to the bottom of the tank by a $\frac{3}{4}$ -inch lead pipe coupled by a $\frac{3}{4}$ -inch iron pipe to a boiler placed outside the building, whilst the overflow from the tank falls directly into the washing-tank, a wooden vat, 12 feet in diameter by 10 feet in depth, over which the acid-tank is situated. The pump of the filter-press, driven by a belt and gearing from the motor countershaft, is fitted with a $1\frac{1}{2}$ -inch suction-pipe giving off three $1\frac{1}{2}$ -inch branches provided with cocks, one running to the bottom of the acid-tank, one to the bottom of the washing-tank, and the third coupling up to the $1\frac{1}{2}$ -inch clean-water service-pipe; whilst the discharge-pipe of the press is provided with a length of hose and can be connected up, either to a $1\frac{1}{2}$ -inch pipe leading to the washing tank, or to a pipe running to the waste gutter outside the building. Of the ball-mills, one is 32 inches in diameter and is driven by belting from the motor countershaft, and the other is 24 inches in diameter and is worked by hand. The drying furnaces are 6 feet in length by 3 feet in width, the reverberatory furnace is 4 feet 6 inches in length by 3 feet in width, and the two smelting furnaces are each 16 inches by 15 inches by 2 feet 6 inches in depth. The tilting furnace is provided with a large plumbago crucible and serves the same purpose as the reverberatory furnace, the only difference being that, whilst with the reverberatory furnace the process is intermittent, with the tilting furnace it is continuous. Bunkers for supplying the furnaces are built outside the clean-up room and are fitted with metal-lined shoots delivering coke or coal as required directly into the building.

The zinc-slimes from the extractor-boxes, after treatment in the acid-tank, are pumped through the filter-press, and the overflow

from the press is discharged to the washing-tank. Clean water is then pumped through the press and the overflow is again run to the washing-tank, where any of the zinc-slimes that may have escaped from the press are allowed to settle, and, after the clear liquid in the tank has either been siphoned to waste or pumped to waste through the press, are again pumped through the press. The cakes from the press are taken to the drying-furnaces, and after thorough drying and calcining to get rid of any excess of zinc, are mixed with fluxes and treated either in the reverberatory furnace or in the tilting furnace, the result being a crude gold which is refined by remelting with suitable fluxes in the smelting furnaces; whilst the slags, formed in the last two processes, are ground in the ball-mills and taken to the slag washing-tank, where they are passed with water over riffles and any particles of gold held up in the slag are caught and collected ready for refining with the next charge of gold.

There are two water-services to the extractor-house and clean-up room, one, brought by a 2-inch pipe from the return-water collecting-tanks, supplying a $1\frac{1}{2}$ -inch standpipe to each of the extractor-boxes and then passing on to the clean-up room where it gives off a 2-inch branch to the acid-tank and a $1\frac{1}{2}$ -inch branch running to the zinc-lathe and to the slag washing tank, the other, brought by a $1\frac{1}{2}$ -inch pipe from the drinking-water service-main, supplying $1\frac{1}{2}$ -inch branches to the sinks in the laboratory and cyanide manager's office, to the boiler generating steam for the acid-tank, and to the pump of the filter-press. The pump-room contains the solution-pumps supplying the concentrates, sands, and slimes treatment-tanks, the pump pumping the slimes gold-bearing solutions from the slimes filter-tanks to the slimes extractor-boxes, a drainage-pump, and the return water-pumps. There are five sets of solution pumps; three for the sands and concentrates treatment-plant, one each for strong, medium, and weak solutions; and two for the slimes treatment-plant; each set consisting of two $5\frac{1}{2}$ -inch centrifugal pumps mounted on a common baseplate, and coupled directly by claw-clutch couplings to the armature-shaft of the motor bolted to the base-plate between each two pumps. The motors of the first three sets of solution-pumps are of 25 brake-HP. each, but those of the two slimes solution-pumps are of 50 brake-HP. each, owing to the deliveries of the two pumps of each of the first three sets being coupled up in parallel to their respective delivery-mains, whilst in the two slimes-sets the two pumps of each set are coupled up in series, the delivery of the first pump of each set to the suction of the second pump of that set. Four-inch suction- and delivery-pipes are connected to

each pump, each suction-pipe tapping two solution-tanks and conveying solution to the pumps to be delivered to the concentrates, sands, and slimes treatment-tanks; the strong-solution pump being fitted, in addition, with a 4-inch by-pass and valves enabling it to be used, when not pumping solution to the treatment-tanks, as a circulating-pump for the two strong-solution tanks. The drainage-pump is exactly similar to the three solution-pumps supplying the sands and concentrates treatment-tanks, and is used for pumping up to the medium extractor-boxes the contents of the drainage-sump in the pump-room floor, which receives all the washings from the extractor-house and pump-room floors, and any solution leaking or spilt on to them; these floors are constructed of granolithic paving and are carefully graded to lead the drainage to the sump. The return-water pumps, five in number, of the three-throw vertical type, one large, two intermediate, and two small, are each driven through spur-gearing by a motor mounted on an extension of the pump bedplate, and have been designed to pump against a vertical head of 90 feet. The large pump has rams $21\frac{1}{2}$ inches in diameter by 18 inches stroke, and, driven at a speed of 26 revolutions per minute by a motor of 68 brake-HP., has a capacity of 100,000 gallons per hour; the two intermediate pumps have rams $15\frac{1}{2}$ inches in diameter by 15 inches stroke, and driven at 32 revolutions per minute by motors of 41 brake-HP. have each a capacity of 60,000 gallons per hour, whilst the two small pumps have rams $13\frac{1}{2}$ inches in diameter by 12 inches stroke, and driven at a speed of 40 revolutions per minute by motors of 28 brake-HP. have each a capacity of 40,000 gallons per hour. The total capacity of the pumps is thus 300,000 gallons per hour, or 36,000 tons per day of 24 hours. The pumps are supplied through an 18-inch main by the two return-water collecting-tanks and deliver into two 12-inch mains, running, one to supply the four low-level return-water tanks, and the other to supply the high-level return-water tank. Situated outside the extractor-house, on the north side, are the solution-tanks, eight in number, of which two tanks, each 40 feet in diameter by 10 feet in depth, contain the solutions for the slimes treatment-plant, and the remaining six tanks, 30 feet in diameter by 8 feet in depth, hold the solutions for the sands and concentrates treatment-plant, two tanks each for strong, medium, and weak solutions. A horizontal platform runs above the centre-line of the tanks and is reached by a ladder from the ground-level, and by two branch-platforms, one from the clean-up room and the other direct from the extractor-house, the latter on its passage through the pump-room being slung from the tie-beams of the roof-trusses. These platforms, besides giving ready

access to the tanks, carry the overflow-mains from the extractor-boxes and the circulating by-pass from the strong-solution pump.

Return-Water Tanks.—The return-water tanks comprise the collecting-tanks and the high- and low-level supply-tanks. The two return-water collecting-tanks, 20 feet in diameter by 10 feet in depth, are supplied by the overflow from the slimes settling-tanks and from the spitzkasten concentrating the washings from the crusher-station and from the mill belt, by the water pumped up from the mine at the central shaft, and by a 12-inch make-up delivery-main coupled up to two motor-driven 45-HP. reciprocating pumps located at one of the Company's dams. They are fitted with an overflow-launders running to waste and with an 18-inch main connected to the suctions of the return-water pumps. The four low-level supply-tanks, supported by a staging 29 feet 1 inch in height, built up of eight rows of trestling strengthened and rendered rigid by rails and diagonal bracing and securely held together by tie-bolts, are 30 feet in diameter by 8 feet in depth, are supplied by a 12-inch main from the return-water pumps, and are fitted with an overflow-launders running to the return-water collecting-tanks, and an 11-inch delivery-main supplying a 9-inch branch to the battery water-service and a 6-inch branch to the concentrates and sands treatment-tanks. The high-level supply-tank, carried on a hexagonal staging, 58 feet 6 inches in height and strengthened and held together by rails, diagonal- and wind-bracing, and tie-bolts, is 25 feet in diameter by 8 feet in depth, receives its supply from a 9-inch pipe connected by a reducing-piece to the other 12-inch main from the return-water pumps, and has an overflow-launders running to the lower tanks, and a 9-inch delivery-main giving off:—a 3-inch branch supplying the mill fire-service and the water-service to the tripper of the belt feeding the mill-bins, a 5-inch branch to the spitzluten supply-tanks, a 6-inch branch to the slimes treatment-plant, a 2-inch branch to the ash storage-bins, and a 5-inch branch to the crusher-station.

Main Waste Conveyor to Waste Dump.—The main waste conveyor to the dump is divided into three parts, known respectively as conveyors H, K1, and K2. Conveyor H, starting at the crusher-station below the headend of conveyor G, runs horizontally, passing first through the weighing-room where a Blake-Denison automatic weigher records the amount of waste-rock delivered to the belt by conveyor G, and then below the two ash storage-bins, from which some 60 tons of ash per day are fed on to the belt, before discharging into a hopper delivering the waste-rock and ash to conveyor K1. The belt is 30 inches in

width and 454 feet in length between pulley-centres, and, driven from its head-end by a 50-HP. motor at a speed of 275 feet per minute, has a carrying capacity of 114 tons per hour. Conveyor K1 runs horizontally, in a trench at right-angles to conveyors H, L1, and L2, for a distance of 110 feet, receiving the waste-rock and ashes delivered to it by conveyor H, and the residue-sands brought from the concentrates and sands treatment-plant by conveyors L1 and L2, before rising to the ground-level through a curve of 250 feet radius and proceeding at an incline of 19.5° , to a height of 60 feet 6 inches above ground-level, carried by steel channels supported by three light steel trestles and a tower, built up of steel angle-bars strongly and rigidly braced together, carrying, not only the ends of the belt-platform of conveyors K1 and K2, but a motor-house containing two 50-HP. motors, one driving the head-end of conveyor K1 and the other the tail-end of conveyor K2. This belt is 30 inches in width and 355 feet in length between pulley-centres, and, running at a speed of 320 feet per minute, can deliver a maximum of 284 tons per hour to a shoot feeding the waste-rock, ash, and residue sands on to conveyor K2. Conveyor K2, carried upwards at an inclination of 18° by a light steel girder, formed of two inverted bowstring-trusses, passing in a single span of 195 feet from the tower just mentioned to an end tower built up of steel angle bars strengthened by steel angle-bar rails and diagonal bracing and anchored to the ground by steel guy-ropes, is 30 inches in width and 197 feet in length between pulley-centres, and, driven at its tail-end at a speed of 320 feet per minute by a 50-HP. motor, has a carrying-capacity of 284 tons per hour. A mast, constructed of steel angle-bars strengthened by transverse and cross bracing, and guyed from a revolving collar on its upper end, by steel ropes anchored to solid concrete foundations, is riveted to a turntable revolving through an angle of 180° on a steel pivot carried by a platform on the top of the end tower, and has, bolted to its lower end, a boom 100 feet in length, built up of light steel sections riveted together and supported in a horizontal position by steel ropes fixed to the top of the mast and secured to the boom at intervals of 20 feet. A hopper bolted to the mast at a height of 130 feet from the ground receives the discharge from the head-end of conveyor K2, and, after dropping the waste-rock, residue-sands, and ashes directly to the ground until the end tower is completely buried, is adjusted to feed on to conveyor P, a 30-inch belt, which, driven at a speed of 320 feet per minute by a 10-HP. motor situated on the end tower, has a carrying-capacity of 284 tons per hour, and, being supported on and revolving

with the boom, distributes the waste-rock, ash, etc., over a large area of ground.

The Author desires to acknowledge his indebtedness to Mr. J. W. Forster, who was in charge of the construction of the plant described in this Paper, and to his assistant Mr. R. J. H. Allen, and other members of his staff who have assisted him in various ways.

The Paper is accompanied by twenty-two tracings, from which Plates 4 and 5 have been prepared; by an album of photographs, illustrating the construction of the plant, which may be seen in the Library of the Institution and by the following Appendixes.

APPENDIXES.

APPENDIX I.

COSTS OF THE PLANT.

	<i>Summary.</i>				
	£	s.	d.	£	s.
Central power-plant :—					
Coal-bunker, crusher and elevator	2,711	10	0		
Central steaming-station	51,929	13	0		
Central power-station	101,224	9	0		
Circulating-water plant	15,379	0	0		
				171,244	12

Ore-handling and treatment plant :—					
Mechanical haulage	3,696	0	0		
Headgear of central shaft	9,181	0	0		
Crusher-station	26,494	0	0		
Mill	57,756	0	0		
Tailings-wheel	5,594	0	0		
Cyanide plant	44,437	0	0		
Slimes plant	20,453	10	0		
Extractor-house	18,703	0	0		
Return-water tanks	2,969	4	0		
Conveying-plant	27,985	0	0		

217,268 14

£388,513 6

Coal-bunker, Coal-crusher, and Elevator.

Earthwork and masonry :—	£	s.	d.	£	s.	d.
Excavations	179	0	0			
Masonry foundations and retaining-walls	527	10	0			
				706	10	0
Timberwork :—						
Timber for coal-bunkers and elevator building	429	0	0			
Erection, etc.	881	0	0			
				1,310	0	0
Ironwork :—						
Coal-crusher	260	0	0			
Coal-elevator	280	0	0			
Erection, etc.	100	0	0			
				640	0	0
Electric-light installation :—						
Cables, etc.				55	0	0

£2

Central Steaming Station.

Earthworks and masonry :—	£	s.	d.	£	s.	d.
Excavations	302	11	0			
Masonry foundations	1,979	7	0			
				2,281	18	0
Steel buildings :—						
Boiler-house, economizer-house, and pump- room	3,467	0	0			
Erection	948	0	0			
				4,415	0	0
Water-tube boilers :—						
Ten Heine boilers	12,060	13	0			
Twenty Jukes stokers	6,439	12	0			
Two motors, line-shaft and gear	1,738	17	0			
Floor-plates	493	9	0			
Erection of boilers—brickwork	2,154	7	0			
" " " —ironwork	1,012	2	0			
				23,899	0	0
Superheaters :—						
Four Davy-Paxman superheaters	3,333	7	0			
Four Jukes stokers	1,260	0	0			
Erection of superheaters—brickwork	860	19	0			
" " " —ironwork	269	12	0			
				5,723	18	0
Economizer :—						
Green economizer (1,200 tubes)	3,760	15	0			
Erection of economizer—brickwork	863	4	0			
" " " —ironwork	203	14	0			
Belting	25	0	0			
				4,852	13	0
Brickwork to flues, floor-paving, etc.				1,018	15	0
Ash-conveyor and elevator, ash-bins, etc. :—						
Ash-conveyor	580	0	0			
Ash-elevator	236	0	0			
Erection	209	2	0			
Ash-bin and shoots	375	0	0			
				1,400	2	0
Steam-pipes :—						
Piping	2,330	3	0			
Erection	450	0	0			
				2,780	3	0
Induced-draught plant :—						
Fans, smoke-stack, etc.	2,327	0	0			
Belting	30	0	0			
Erection	290	15	0			
				2,647	15	0
Boiler feed-pumps and heater :—						
Three Weir pumps	1,403	8	0			
Heater	165	15	0			
Hot-well and measuring-tank	225	0	0			
Erection	155	0	0			
				1,949	3	0
Carried forward				£50,968	7	0

Central Steaming Station—continued.

	£	s.	d.	£	s.	d.
Brought forward				50,968	7	0
Oil-filtering plant :—						
Tanks, cabinets, pumps, piping, etc.	215	0	0			
Timber framing (labour and material)	156	6	0			
Erection	145	0	0			
				516	6	0
Wattmeters				100	0	0
Electric-light installation, cables, etc.				345	0	0
				£51,929	13	0

Central Power Station.

Earthworks and masonry :—						
Excavations	540	0	0			
Masonry foundations	5,950	0	0			
Engine capstones	2,961	0	0			
				9,451	0	0
Steel buildings, etc. :—						
Engine-room	5,738	0	0			
15-ton hand travelling-crane	623	0	0			
Erection	1,140	0	0			
Painting	498	10	0			
Carpenter's work in engine-room, template, etc.	870	0	0			
Granolithic paving	922	7	0			
Chequered plates	550	0	0			
				10,341	17	0
Mill-engines :—						
Engines A and B with shafting, spares, etc.	14,133	11	0			
Erection of engine A with shafting, clutches, etc.	462	12	6			
Erection of engine B, driving-ropes, etc.	357	17	6			
Driving-ropes for engine B	127	10	0			
				15,081	11	0
Electric generating-plant :—						
Three 350-kilowatt sets, engines, dynamos and spares	12,046	0	0			
Erection	630	0	0			
				12,676	0	0
Main switchboard, etc. :—						
Switchboard	1,598	3	0			
Wattmeters	313	10	0			
Cables	715	0	0			
Lightning arresters	1,805	0	0			
Erection, etc.	275	0	0			
				4,706	13	0
Fifty-drill compressor :—						
Compressor	10,283	10	0			
Erection	497	10	0			
				10,781	0	0
Carried forward				£63,038	1	0

Central Power Station—continued.

		£	s.	d.
	Brought forward	63,038	1	0
Twenty-five-drill compressor :—				
Compressor	5,779 10 0			
Erection	322 15 0			
		6,102	5	0
Direct-acting conical drum-hoist :—				
Engine complete with spares	15,300 0 0			
Erection	710 18 0			
		16,010	18	0
Condensing-plant :—				
Condensers, feed-heaters, air-pumps, etc.	10,850 0 0			
Erection	526 0 0			
		11,376	0	0
Piping :—				
Steam- and exhaust-piping, valves, etc.	3,100 0 0			
Erection	477 15 0			
		3,577	15	0
Painting engines, condensers, pipes, etc.		769	10	0
Electric-light installation, cables, etc.		350	0	0
		£101,224	9	0

Circulating-water Plant.

Earthworks and masonry :—				
Excavations	3,360 0 0			
Brickwork, concrete, etc.	3,950 0 0			
		7,310	0	0
Pumping-plant :—				
Centrifugal pumps and turbine	2,556 0 0			
Motors, switchboard, etc.	912 0 0			
Piping	300 0 0			
Erection	226 10 0			
		3,994	10	0
Timbering :—				
Timbering of shaft	3,150 0 0			
„ „ tunnel	400 0 0			
		3,550	0	0
Erection of pump-house		258	18	0
Condenser-sump		225	12	0
Electric light installation		40	0	0
		£15,379	0	0

Mechanical Haulage.

From Eastern and Western Shafts to Central Shaft.

Earthworks, masonry, etc. :—				
Embankments	825 0 0			
Masonry foundations	367 0 0			
		1,192	0	0
Permanent-way :—				
Rails, points, fish-plates, bolts, etc.	389 0 0			
Track-laying	300 0 0			
		689	0	0
Carried forward		£1,881	0	0

Mechanical Haulage—continued.

	£	s.	d.	£	s.	d.
Brought forward	1,881	0	0			
Trestling, motor-house, platforms, etc. :—						
Timber	420	0	0			
Erection, including supply of tie-bars, bolts, etc.	840	0	0			
				1,260	0	0
Motor, cables, etc.				250	0	0
Electric-light installation				30	0	0
Haulage-ropes, guide-pulleys, etc.				275	0	0
				<u>£3,696</u>	0	0

Headgear of Central Shaft.

Earthworks, masonry, etc. :—						
Excavations	180	0	0			
Masonry foundations	905	0	0			
				1,085	0	0
Framing of headgear, bins, etc. :—						
Pitch-pine	816	0	0			
Oregon pine	1,261	17	0			
Erection, including supply of tie-bolts, bin- lining, etc.	4,243	4	0			
				6,321	1	0
Headgear-pulleys				183	19	0
Track-rails				100	0	0
Electric light installation				50	0	0
Skips, ropes, etc.				1,441	0	0
				<u>£9,181</u>	0	0

Crusher-station.

Earthworks, masonry, etc. :—						
Excavations	497	14	0			
Masonry	2,575	0	0			
				3,072	14	0
Framing of crusher-station, bins, etc. :—						
Oregon pine	3,758	16	0			
Erection of all woodwork	10,193	0	0			
				13,951	16	0
Tanks, trestling, etc. :—						
Timber	239	18	0			
Erection, etc.	480	0	0			
				719	18	0
Ironwork :—						
Five Blake-Marsden 30-inch by 18-inch crushers	3,655	0	0			
Two overhead cranes (8-ton and 5-ton rails) etc.	406	0	0			
Trommels	678	12	0			
Grizzlies	200	0	0			
Erection of above	639	0	0			
				5,578	12	0
Electrical work :—						
Motors and switchboards, erection, etc.	2,671	0	0			
Electric-light installation, cables, etc.	350	0	0			
				3,021	0	0
Driving-belts for crushers				150	0	0
				<u>£26,494</u>	0	0

Mill.

Earthwork, masonry, etc. :—	£	s.	d.	£	s.	d.
Excavation	488	13	0			
Masonry and concrete	3,748	7	0			
				4,237	0	0
Framing of buildings, batteries, bins, etc. :—						
Pitch-pine	6,267	10	0			
Oregon pine and flooring	4,121	18	0			
Erection, including supply of all tie-rods, bolts, bin-lagging, etc.	18,359	0	0			
Cam-shaft pulleys	315	0	0			
Hardwood guides for stamp-stems	560	0	0			
Tables	800	0	0			
				30,423	8	0
Ironwork :—						
Battery-ironwork, including mortar-boxes, stamps, cam-shafts, battery water-service, ore-feeders, copper plates, etc.	13,784	0	0			
Main-line shafting including Seymour clutches, bearings, etc.	3,500	0	0			
Two 5-ton cranes, rails, etc.	446	12	0			
Erection of ironwork	2,000	0	0			
Ball-mill, grinding-pan, clean-up pan, shafting, etc.	1,100	0	0			
Main pipe-line to battery water-service	525	0	0			
Fire-service	500	0	0			
				21,855	12	0
Driving-belts for mill				970	0	0
Electric light installation				270	0	0
				£57,756	0	0

Tailings Wheel.

Earthworks, masonry, etc. :—						
Excavations	274	16	0			
Masonry, capstones, etc.	801	0	0			
				1,075	16	0
Timberwork :—						
Timber	390	0	0			
Erection of platforms, buckets, etc.	660	0	0			
				1,050	0	0
Ironwork :—						
Wheel 72 feet in diameter	2,433	0	0			
Erection	886	0	0			
Tension-carriage, rails, etc.	77	4	0			
				3,396	4	0
Driving-rope				42	0	0
Electric light installation				30	0	0
				£5,594	0	0

Cyanide Plant.

Earthworks, masonry, etc. :—	£	s.	d.	£	s.	d.
Excavations	992	7	0			
Masonry foundations, concrete, capstones, etc.	6,910	15	0	7,903	2	0
Timberwork :—						
Timber	3,212	0	0			
Erection, etc.	6,422	8	0	9,634	8	0
Ironwork :—						
Tanks, columns, girders, etc.	21,250	0	0			
Piping, cocks, etc.	1,634	10	0			
Erection	3,140	0	0			
Spitzluten water-supply tanks	100	0	0	26,124	10	0
Filter-cloths				525	0	0
Electric light installation, cables, etc.				250	0	0
				£44,437	0	0

Slimes Plant.

Earthworks, masonry, etc. :—						
Excavations	997	12	0			
Masonry, asphalt, etc.	1,992	16	0	2,990	8	0
Timberwork :—						
Timber for platforms, launders, etc.	1,031	4	0			
Erection, etc.	2,062	8	0	3,093	12	0
Ironwork :—						
Slimes-tanks	5,987	12	0			
Solution-tanks	1,072	0	0			
Tank-fittings	766	0	0			
Slimes-pumps	690	0	0			
Piping, valves, etc.	2,366	0	0			
Erection, etc.	2,876	18	0	13,758	10	0
Lime-feeder :—						
Building, plant, erection, etc.				356	0	0
Electric light installation, cables, etc.				255	0	0
				£20,453	10	0

Extractor-House.

Earthworks, masonry, etc. :—						
Excavations	1,149	17	0			
Masonry, concrete, etc.	491	0	0			
Granolithic paving	703	0	0	2,343	17	0
Timberwork :—						
Timber	1,027	7	0			
Erection of building, extractor-boxes, etc.	2,054	15	0	3,082	2	0
Carried forward				£5,425	19	0

Extractor-House—continued.

	£	s.	d.	£	s.	d.
Brought forward	.	.	.	5,425	19	0
Ironwork :—						
Filter-press, ball-mill, zinc-lathe, shafting, } etc. }	400	3	0			
Solution-pumps	1,040	0	0			
Return-water pumps	3,624	0	0			
Pipes, valves, fittings, etc.	2,111	0	0			
Erection, etc.	715	8	0			
				7,890	11	0
Furnaces :—						
Ironwork, erection, etc.				926	0	0
Electrical work :—						
Motors, switchboards, erection, etc.	4,240	10	0			
Electric light installation, cables, etc.	220	0	0			
				4,460	10	0
				£18,703	0	0

Return-water Tanks.

Earthworks, masonry, etc. :—						
Excavations	30	16	0			
Masonry foundations	368	10	0			
				399	4	0
Trestling, tanks, etc. :—						
Timber for trestling, tanks, etc.	675	0	0			
Erection	1,309	0	0			
				1,984	0	0
Ironwork :—						
Piping, fittings, etc.	326	0	0			
Erection, etc.	225	0	0			
				551	0	0
Electric light installation				35	0	0
				£2,969	4	0

Conveying-belts, Trestling, etc.

Earthworks, masonry, etc. :—						
Excavations	166	0	0			
Masonry foundations, retaining-walls, etc.	1,603	0	0			
				1,769	0	0
Belts, idlers, etc.				13,377	0	0
Motors				3,116	0	0
Steelwork of trestles, etc.				3,192	0	0
Erection of belts, motors, steelwork, etc.				2,311	0	0
Weighing-machines				900	0	0
Timber trestling :—						
Timber	900	0	0			
Erection, etc.	1,805	0	0			
				2,705	0	0
Electric light installation				160	0	0
Power-cables, erection, etc.				455	0	0
				£27,985	0	0

APPENDIX II.

WORKS AND MAINTENANCE COSTS, ETC.

The following are the works-costs per I.H.P.-hour at the New Kleinfontein central power-station :—

Hauling-engines with a load-factor of 20·8 per cent.	cost	0·86d.	per I.H.P.-hour.
Electric generators	" " "	40·5	" " " 0·38d. " " "
Mill-engines	" " "	75·7	" " " 0·37d. " " "
Air-compressors	" " "	76·0	" " " 0·39d. " " "

The works-costs averaged over the total output of the plant are 0·423d. per I.H.P.-hour.

It will be seen from the foregoing that a large portion of the plant is working under favourable conditions of load-factor, as out of a total of 52,263 I.H.P.-hours per day, 46,083 I.H.P.-hours represent plant running under a practically constant load, such as the mill-engines and air-compressors.

The total costs per I.H.P.-hour for the steam power-plant are :

	Hauling-Engines.	Mill-Engines, Air-Compressors and Generators.	Average.
	Pence.	Pence.	Pence.
Works-costs	0·860	0·380	0·423
Maintenance	0·102	0·102	0·102
Management	0·050	0·050	0·050
	1·012	0·532	0·575
Interest and depreciation . . .	0·225	0·225	0·225
Total cost	1·237	0·757	0·800

APPENDIX III.

RESULTS OF TRIALS OF THE PLANT.

Trial of No. 2 Boiler.

Date of trial	21 May, 1905.
Duration of trial	5·58 hours.
Actual time mechanical stokers were travelling	5·42 "
Velocity of stokers	5 feet per hour.
Depth of coal on grate	6 inches.
Grate-surface; width, 3 feet 8 inches; effective length, 9 feet	33 square feet.
Number of stokers	2
Total grate-area	66 square feet.
Water heating-surface	2,150 " "
Ratio of water heating-surface to grate-area	32·58
Steam-pressure in boiler, by gauge	{ 160 lbs. per square inch.
Absolute steam-pressure	{ 172 lbs. per square inch.
Draught at base of stack in inches of water	1½ inch.
Temperature of feed-water	240° F.
Total amount of coal consumed (85 per cent. "Apex" and 15 per cent. "St. George's")	5,081·25 lbs.
Moisture in coal (1·3 per cent. "Apex" and 1·7 per cent. "St. George's")	69·11 "
Dry coal consumed	5,012·14 "
Total refuse dry (23 per cent. "Apex" and 12 per cent. "St. George's")	1,070·38 "
Total combustible	3,941·76 "
Calorific value of fuel	8,308 B.Th.U.
Dry coal consumed per hour	924·7 lbs.
Dry coal consumed per square foot of grate-surface per hour	14·01 "
Combustible consumed per hour	727·3 "
Percentage of moisture in steam	3·7
Total quantity of water apparently evaporated	34,400 lbs.
Water actually evaporated corrected for quality of steam	33,127·2 lbs.
Water actually evaporated corrected for quality of steam per hour	6,112·03 "
Equivalent evaporation-factor	1·02
Equivalent water evaporated into dry steam from and at 212° F.	33,789·7 lbs.
Equivalent water evaporated into dry steam from and at 212° F. per hour	6,234·13 "
Equivalent water evaporated into dry steam from and at 212° F. per square foot of heating surface per hour	2·9 "
Water actually evaporated per pound of dry coal from actual pressure and temperature	6·69 "
Equivalent water evaporated per lb. of dry coal from and at 212° F.	6·74 "
Equivalent water evaporated per pound of combustible from and at 212° F.	8·56 "
Efficiency of boiler	78·4 per cent

STEAM-CONSUMPTION TESTS OF ENGINES AT THE CENTRAL ENGINE-ROOM.

Mill-Engines.—With the full number of 200 stamps dropping, these engines were found, when running at 72 revolutions per minute with steam at a pressure of 130 lbs. per square inch at the engine stop-valve, but with no superheat, and with a vacuum equal to 17 inches at the engine exhaust, to develop :—

The A engine (direct drive) 856 I.H.P. ; and the B engine (rope-drive) 677 I.H.P. with a steam-consumption of 13·43 lbs. per I.H.P.-hour.

It will thus be seen, assuming that the amount of sands and water raised by the tailings-wheel is constant, and also that the average drop of the stamps is constant, that there is a difference of 21 I.H.P. in favour of the direct-coupled engine as compared with the rope-driving engine, an amount equal to 3·2 per cent. of the total I.H.P. required.

50-Drill Compressor.—This engine, when running at 55 revolutions per minute with steam at a pressure of 130 lbs. per square inch at the engine stop-valve, but with no superheat, and with a vacuum equal to 17 inches at the engine exhaust, develops 1,100 I.H.P. with a steam-consumption of 14·0 lbs. per I.H.P.-hour.

Electric Generating Engines.—These engines, when running at 360 revolutions per minute with steam at a pressure of 130 lbs. per square inch at the engine stop-valve, but with no superheat, and with a vacuum equal to 17 inches at the engine exhaust, each develop 610·7 I.H.P., with a steam-consumption of 13·8 lbs. per I.H.P.-hour.

Direct-Acting Winding-Engine.—This engine, when running at 30 revolutions per minute with steam at a pressure of 130 lbs. per square inch at the engine stop-valve, but with no superheat, and with a vacuum equal to 17 inches at the engine exhaust, develops 416·25 I.H.P. with a steam-consumption of 14·5 lbs. per I.H.P.-hour.

(Paper No. 3659.)

“The Efficiency of the Shone System of Pumping.”

By CHARLES LESLIE COX.

THIS Paper was prepared with the object of adding to the data at present somewhat scarce¹ concerning the actual working of the Shone system of pumping, and embodies the results of careful tests carried out by the Author on the sewage-pumping plant of the Gosport and Alverstoke Urban District Council.

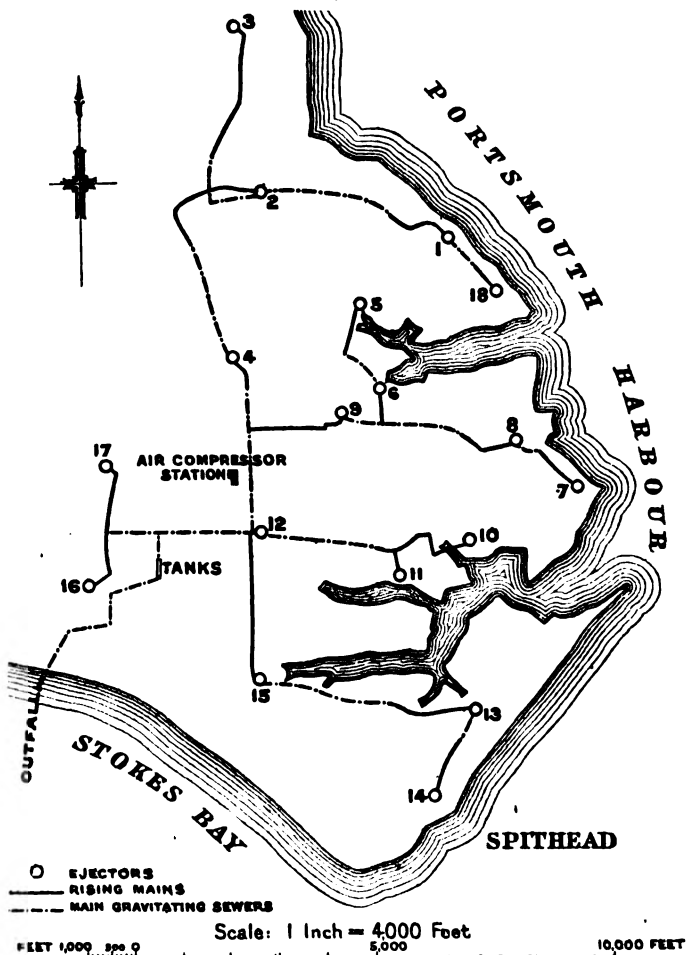
The district referred to has an area of 3,843 acres and a population of 30,000 persons. The difficulties of drainage were considerably increased by the flat conformation of the ground (the highest point drained being only 20 feet above, and the lowest point 2 feet below high-water level of spring-tides) and by the intersection of the town by creeks left practically dry at low water.

It was eventually decided to divide the district into areas and to adopt the Shone system of pumping by compressed air supplied from one central station; the scheme provides for the drainage of 2,200 acres and for an estimated population of 40,000 persons, storm-water being excluded as far as possible. As shown in *Fig. 1*, eighteen ejector-stations are provided, each station having ejectors in duplicate, varying in capacity between 50 gallons and 800 gallons. The total length of the sewers is approximately 30·3 miles, the rising-mains 5·5 miles, and the air-mains 11 miles. The rising-mains vary between 5 inches and 15 inches in diameter and the air-mains between 2½ inches and 12 inches. The compressor-plant consists of two twin sets of direct-acting compressors, each set of 160 I.H.P. and comprising two condensing steam-jacketed and covered steam-cylinders and two water-jacketed and covered double-acting air-cylinders with coupled fly-wheels, the safe maximum speed being 200 revolutions per minute. The inlet and delivery of the air-cylinder are governed by Corliss mechanically-controlled valves. Steam is supplied from two Galloway boilers, each 7 feet 6 inches in diameter and 28 feet in length, one boiler being connected to a two-cell back-feed Horsfall destructor

¹ See J. F. Brunton, “Notes on the Working of the Shone System of Sewerage at Karachi.” Minutes of Proceedings Inst. C.E., vol. clx, p. 211.

consuming 10 tons per cell per 24 hours. The sewage discharges from a cast-iron outfall-pipe 36 inches in diameter into the Solent, 600 feet beyond high-water mark, after passing through three

Fig. 1.



PLAN SHOWING EJECTORS, RISING-MAINS, AND MAIN SEWERS.

covered septic-tanks having a total capacity of 1,200,000 gallons. Mr. R. St. G. Moore, M. Inst. C.E., was the engineer for the scheme, and the total cost of the works amounted to £110,000.

Although the engines were started in June 1904, the district, at

the date of the tests (May 1906), was not wholly connected up, the average weekly flow being only about 3,000,000 gallons.

The air-mains were laid with every possible care and were tested in sections with a pressure of 40 lbs. per square inch, but there must always be some leakage of air in its transmission to the ejectors. This loss, together with the loss by leakage in the automatic, alternating, and stop-valves at the ejectors, was ascertained in the following manner:—On Sunday morning 29th April, 1906, the inlet- and delivery-valves at all the ejector-stations were shut down, preventing the ejectors from discharging, and at 8 a.m. the compressors were stopped. After allowing a few minutes for the air in the receiver to cool, the air-pressure was read from the gauge and recorded. At the expiration of 1 hour, the pressure then having fallen 5 lbs. per square inch, the engines were restarted and it was found that 362 revolutions of one set of engines were required to make good this loss. After pumping away the sewage accumulated during this test, all the stop-valves on the air-mains at the ejectors were shut down and the engines were again stopped; the fall of pressure during 1 hour was 2·5 lbs. per square inch and this loss was made good by 185 revolutions of one set of engines. In each case deducting, from the number of revolutions required to replace the loss of pressure, 2 revolutions assumed to be required to make good the loss in opening the air stop-valves on restarting the engines, and taking the average speed during all the tests to have been 48 revolutions per minute (Table I, Appendix), or 2,880 revolutions per hour, the revolutions required to make good constant loss by leakage amount to:—

$$\text{First test} \quad \frac{360 \times 100}{2,880} = 12\cdot5 \text{ per cent.}$$

$$\text{Second test} \quad \frac{183 \times 100}{2,880} = 6\cdot35 \text{ per cent.,}$$

the latter being the loss by leakage in the air-mains only and the former the loss in the air-mains and ejector-valves together.

By systematic search along the line of the air-mains in wet weather leaks may be discovered by the bubbles on the surface; and with careful supervision the loss from this cause should be reduced to an inconsiderable amount. The loss in the ejector-valves is more difficult to remedy, the free working of the valves, which are of the piston type, necessitating a slight leakage which is practically unavoidable.



The following particulars relating to the plant are common to all the trials :—

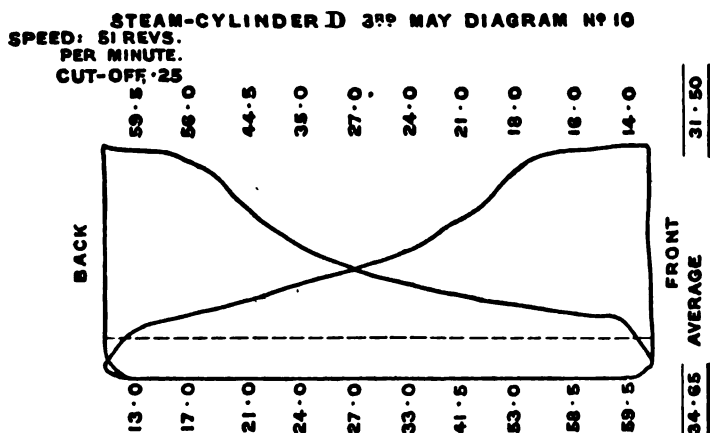
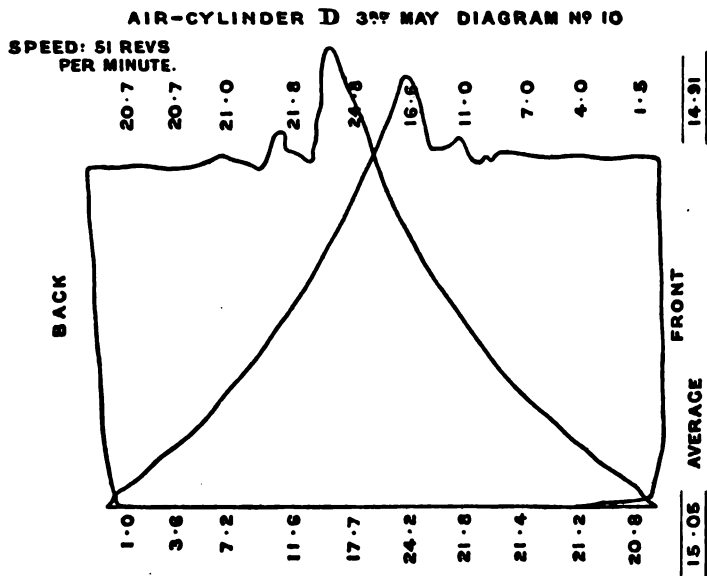
Diameter of steam-cylinders	12·50 inches.
" " air-cylinders	16·00 "
Length of stroke	18·00 "
Cut-off at	0·25 of stroke.
Effective area of steam-cylinders (front)	118·70 square inches.
" " " " (back)	119·60 " "
" " " air- (front)	198·00 " "
" " " " (back)	201·00 " "
" " " " (mean)	199·55 " "
Mean capacity of one air-cylinder	2·08 cubic feet.
Gauge-pressure of air on leaving compressors	22·50 lbs. per sq. in.

During the tests ejector-station No. 3 was completely shut down, there being no sewage flow, as Fort Elson, which discharges into the ejector, was unoccupied. This, however, in no way affects the results. In order to reduce the number of counters required, only one ejector at each station was in use, the other being shut off from the sewage inlet-pipe. At thirteen stations automatic counters were fixed to the levers actuating the air-valves, men being stationed at the remainder to record accurately the number of discharges during the tests. The 2nd, 3rd, and 16th May were the days allocated for the work, readings being taken continuously from 9 a.m. till 3 p.m. Owing to the breakdown of one of the automatic ejector counters the tests on the 2nd May proved abortive, and have not been included in this Paper. Readings of the steam- and air-pressures and temperatures were taken at the air-compressing station at intervals of 15 minutes, and indicator-diagrams were taken from the air- and steam-cylinders every 30 minutes. The air-supply temperature was taken in the fresh-air shaft and that of the compressed air by thermometers inserted in the air-chamber over the cylinders. These readings, together with the other readings taken, are given in Table I. The maximum variation of the air pressure-gauge reading was only 2 lbs. per square inch.

Particulars relating to the ejectors are given in Table II (Appendix), the figures given in column 6 being based upon a series of exhaustive tests made within a few days of the trials. These tests may be summarized as follows :—The air-pressure at the compressor-station was kept constant at 22·5 lbs. per square inch whilst a U tube with a pressure-gauge and thermometer attached was connected to the interior of each ejector in turn, and numerous readings were taken while the ejectors were discharging. The thermometer showed an average temperature in the ejector-bodies of 64° F. The average indicated pressure in the ejectors is shown in column 6 of Table II, and is converted into its equivalent dynamic head in column 7

(Table II). The work done at the ejectors is based upon this head and upon the quantity of sewage discharged.

Figs. 2.



INDICATOR-DIAGRAMS FROM AIR-COMPRESSOR.

The efficiency of the mechanism of the compressing-plant is shown in Table III (Appendix), and specimen indicator-diagrams are given in *Figs. 2*.

The actual quantity of sewage discharged at each ejector during the tests, based upon the capacity of the ejectors and the number of discharges recorded, is shown in Tables IV and V (Appendix). The average head obtained by dividing the sum of the products of head and discharge by the total quantity discharged, gives the average pressure per gallon in the ejectors. From the figures at the foot of Tables IV and V, it will be seen that the horse-power developed at the ejectors was 11.34 HP. on the 3rd May, and 11.94 HP. on the 16th May. The actual efficiency of the system from steam-cylinders to ejectors was therefore

$$\frac{11.34}{29.50} = 0.384 \text{ on the 3rd May,}$$

and
$$\frac{11.94}{30.96} = 0.385 \text{ on the 16th May.}$$

This loss of efficiency arises from many causes, the chief of which are, what may be termed the unavoidable losses due to the heating of the air in compression, and the practical impossibility of using the air at the ejectors expansively, together with the loss by leakage in the air-mains and ejector-valves.

In the formulas relating to the compression of the air at the compressors and its use at the ejectors, the following symbols are used :—

P_a = atmospheric pressure in lbs. per square foot.

p_a = " " " " " inch.

p_1 = absolute pressure of compressed air in lbs. per square inch.

P_1 = " " " " " " " foot.

v_a = volume of 1 lb. of air at pressure P_a and temperature T .

v_1 = " " " " P_1 " " "

T = absolute temperature, Fahrenheit scale.

$c = 53.15$, a constant.

$\gamma = 1.41$.

From the laws relating to gases

$$P_a v_a = c T.$$

In all practical methods of compression the air is heated, and as this heat is lost in transmission through the air-mains by conduction into the surrounding medium it is advisable that the cooling-apparatus should be as efficient as possible. In perfect adiabatic compression the final temperature of the compressed air would be

$$T_1 = T \left(\frac{p_1}{P_a} \right)^{0.71}$$

which would give 234° F. for the 3rd May and 241° F. for the

16th May, whereas the actual temperatures on these dates were 165° F. and 167·2° F. respectively. The amount of work required to heat the air to these temperatures is the excess of work beyond that required to compress the air isothermally, and is the index of the efficiency of the compression-process.

The work done in isothermal compression is:—

$$P_a v_a \cdot \log_e \frac{p_1}{p_a} \text{ foot-lbs. per pound of air.}$$

Based upon the volume of 1 lb. of air at the temperatures in the air-supply and upon the mean capacity of the air-cylinder on 3rd May and 16th May the compression of 1 lb. of free air required 3·204 revolutions and 3·25 revolutions respectively of one set of engines.

The actual work done in compressing 1 lb. of free air on each day of the trials, the theoretical work required for isothermal compression of 1 lb. of air, the efficiency of the compressed air, and the total efficiency of the compression-plant, are shown in Table VI (Appendix).

The average dynamic head at the ejectors was 38·30 feet (Tables IV and V), equivalent to a gauge-pressure of 16·46 lbs. per square inch or 31·16 lbs. per square inch absolute pressure, and the average temperature of the air at the ejectors was 64° F. One pound of air at 64° F. and 31·16 lbs. per square inch absolute pressure has a volume of 6·22 cubic feet, and the possible amount of work it can do in an ejector without expansion is:—

$$\begin{aligned} V_2 \times 144 \times 16\cdot46 \text{ foot-lbs.} \\ = 6\cdot22 \times 144 \times 16\cdot46 = 14,743 \text{ foot-lbs.} \end{aligned}$$

The same amount of air working in adiabatic expansion from a gauge-pressure of 16·46 lbs. per square inch to atmospheric pressure will perform

$$\begin{aligned} \frac{\gamma}{\gamma - 1} \cdot P_1 v_1 \left[1 - \left(\frac{p_a}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right] &= 3\cdot439 \times 27,903 \left[1 - \left(\frac{p_a}{p_1} \right)^{0\cdot29} \right] \\ &= 18,786 \text{ foot-lbs. of work.} \end{aligned}$$

Neglecting slip and clearance, the greatest possible theoretical efficiency of the air working non-expansively at the ejectors is

$$C_s = \frac{14,743}{18,786} = 0\cdot784 \text{ (Table VII, Appendix).}$$

One pound of air at 70° F. and 22·5 lbs. per square inch gauge-pressure has a volume of 5·267 cubic feet.

One pound of air at 76° F. and 22.5 lbs. gauge-pressure has a volume of 5.33 cubic feet.

Taking 1 lb. of air at the gauge-pressure at which it leaves the compressors but at atmospheric temperature, the amount of work obtained non-expansively would be:—

$$5.267 \times 22.5 \times 144 = 17,067 \text{ foot-lbs. on the 3rd May,}$$

$$\text{and } 5.33 \times 22.5 \times 144 = 17,269 \text{ foot-lbs. on the 16th May.}$$

Comparing this with the amount of work obtained from 1 lb. of air working non-expansively at the ejectors, it will be seen that the loss of efficiency of the air as a working-medium during its transmission from the compressors to the ejectors was:—

$$C_5 = \frac{14,743}{17,067} = 0.863, \text{ on 3rd May} \left. \vphantom{\frac{14,743}{17,067}} \right\} \text{(Table VII.)}$$

$$\text{and } C_5 = \frac{14,743}{17,269} = 0.853, \text{ on 16th May}$$

On the 3rd May the air supplied to the compressors, computed from the capacity of the air-cylinders and the number of revolutions, was 141,739.5 cubic feet, which at 70° F. and atmospheric pressure is equivalent to 10,633 lbs. On the 16th May it was 148,503 cubic feet, or 10,984 lbs. The air used at the ejectors, measured by the quantity of sewage displaced, was 56,208 cubic feet on the 3rd May, and 59,128 cubic feet on the 16th May, which at 64° F. and 31.16 lbs. per square inch absolute pressure is equivalent to 9,036 lbs. and 9,506 lbs. respectively.

The ratio of supply to discharge was therefore

$$\frac{9,036}{10,633} = 0.85, \text{ on the 3rd May,}$$

$$\text{and } \frac{9,506}{10,984} = 0.86, \text{ on the 16th May.}$$

These figures corroborate the results obtained on the 29th April—viz., a loss of 12.5 per cent. in the air-mains and ejector-valves, and it has been assumed that the coefficient of efficiency from this cause is $C_4 = 0.875$ (Table VII).

A summary of the different coefficients obtained is given in Table VII, and it will be seen that there is no very great difference between the actual efficiency of the system and the computed efficiency. In comparison with the efficiency of other systems of pumping it must not be forgotten that where applied to a suitable

district the Shone system overcomes many difficulties which in other schemes would probably add materially to the cost.

In conclusion, the Author has not attempted to give any figures relating to the cost of pumping; the permanent automatic counters only show the actual amount pumped and not the number of gallons lifted at each station, and any estimate not based on the work done would be misleading and useless.

The Paper is accompanied by diagrams from which the Figures in the text have been prepared; and by the following Appendix.

[APPENDIX

APPENDIX.

TABLE I.—AVERAGE READINGS AT THE ENGINE-HOUSE DURING THE TRIALS;
9 a.m. TO 3 p.m. ON 3 MAY AND 16 MAY, 1906.

	3 May.	16 May.
Revolutions per minute	47·30	49·58
Air-pressure in lbs. per square inch above atmosphere on leaving compressors	22·50	22·50
Steam gauge-pressure in lbs. per square inch	64·60	72·40
Vacuum in inches	25·50	24·50
Temperature of air in air-supply duct °F.	70	76
" " leaving compressors	165	167·2
" of cooling water	88	85·8
" hot-well	117	122·1
" air at ejectors	64	64

TABLE II.—DETAILS OF EJECTORS, ETC.

1	2	3	4	5	6	7
Ejector Number.	Capacity of Ejector.	Diameter of Rising- Main.	Time taken to Discharge.	Initial Velocity of Sewage in Rising-Main.	Average Gauge- Pressure of Air in Ejector- Bodies.	Dynamic Head Equivalent to Gauge- Pressure.
	Gallons.	Inches.	Seconds.	Feet per Second.	Lbs. per Square Inch.	Feet.
1	100	6	32	2·54	19·00	44·19
2	250	10	25	2·93	17·00	39·53
3	50	5	..	..	..	..
4	400	10	25	4·70	17·00	39·53
5	50	5	20	2·93	17·50	40·07
6	150	7	23	3·91	16·30	37·90
7	250	8	23	4·89	18·50	43·02
8	250	9	25	3·62	18·60	43·25
9	800	15	27	3·80	17·00	39·53
10	200	8	34	2·69	19·00	44·19
11	250	9	25	3·62	17·30	40·23
12	700	15	25	3·72	8·00	18·60
	200	8	26	3·52	16·70	38·83
	50	5	25	2·34	14·50	33·72
	500	12	25	4·07	17·60	40·93
	50	6	21	4·76	16·30	37·90
		7	14	4·28	15·30	35·58
		5	18	3·25	14·60	33·95

TABLE III.—EFFICIENCY OF MECHANISM OF COMPRESSOR.

Date.	Steam.		Air.		Efficiency. C ₁
	Average Pressure by Indicator-Diagram.	HP.	Average Pressure by Indicator-Diagram.	HP.	
3 May . .	Lbs. per Square Inch. 28·80	29·50	Lbs. per Square Inch. 15·30	26·25	0·890
16 May . .	28·80	30·96	15·00	26·97	0·871

TABLE IV.—TEST OF 3 MAY, 1906, 9 a.m. TO 3 p.m.

Ejector Number.	Discharge during Test.	Dynamic Head (Table II, Col. 7).	Head × Discharge.
	Gallons.	Feet.	
1	7,800	44·19	344,682
2	13,500	39·53	533,655
3	..	..	..
4	17,200	39·53	679,916
5	5,550	40·07	222,389
6	16,650	37·90	631,035
7	30,250	43·02	1,301,350
8	50,000	43·25	2,162,500
9	80,000	39·53	3,162,400
10	12,600	44·19	556,794
11	10,250	40·23	412,357
12	35,000	18·60	651,000
13	18,600	38·83	722,238
14	6,800	33·72	229,296
15	34,500	40·93	1,412,090
16	3,250	37·90	123,175
17	4,000	35·58	143,175
18	5,350	33·95	181,632
	351,300	..	13,469,869

$$\text{Average head} = \frac{13,469,869}{351,300} = 38·34 \text{ feet.}$$

38·34 feet is equivalent to an average pressure of 16·48 lbs. per square inch.

$$\text{HP. developed at ejectors} = \frac{13,469,869 \times 10}{33,000 \times 6 \times 60} = 11·34 \text{ HP.}$$

TABLE V.—TESTS OF 16 MAY, 1906. 9 a.m. to 3 p.m.

Ejector Number.	Discharge during Test.	Dynamic Head. Table II, Col. 7.	Discharge × Head.
1	Gallons. 6,500	Feet. 44·19	287,235
2	11,000	39·53	434,830
3	..	..	..
4	12,800	39·53	505,984
5	4,350	40·07	174,304
6	18,150	37·90	687,885
7	29,000	43·02	1,247,580
8	53,250	43·25	2,303,060
9	84,000	39·53	3,320,520
10	12,600	44·19	556,794
11	9,750	40·23	392,242
12	35,000	18·60	651,000
13	34,000	33·83	1,120,220
14	2,050	33·72	69,126
15	37,500	40·93	1,534,880
16	8,050	37·90	305,095
17	6,800	35·58	243,712
18	4,750	33·95	161,262
	369,550		14,195,729

$$\text{Average head} = \frac{14,195,729}{369,550} = 38·25 \text{ feet.}$$

38·25 feet is equivalent to an average pressure of 16·44 lbs. per square inch.

$$\text{HP. developed at ejectors} = \frac{14,195,729 \times 10}{33,000 \times 6 \times 60} = 11·94 \text{ HP.}$$

(*Students' Paper No. 572.*)¹

"The Modern Steam-Turbine."

By ARNOLD FREAN HARRISON, M.Sc., Stud. Inst. C.E.

IN view of the rapidly extending adoption of the steam-turbine as a means of obtaining motive power, the Author endeavours to present in the following Paper, a general description of the best-known types of this class of motor, with some of the reasons for the construction peculiar to each.

The steam-turbines of the present day are the result of development along two distinct lines, and fall naturally into two main groups, viz., the "impulse" or "action" group, which has developed from the De Laval turbine, invented in 1883, and the "impulse-reaction" group, which embodies the principle of the Parsons turbine introduced in 1884.

Every turbine derives its power from changes in the motion of the steam; thus the driving-force in a turbine is not the steam-pressure but the velocity due to that pressure. In the "impulse" class of turbine, the steam is completely expanded, and acquires its full velocity in the nozzles before it is passed to the vanes at all; in the "impulse-reaction" class, on the other hand, velocity is being generated continually throughout the passage of the steam from the throttle to the exhaust-pipe, each vane and guide-blade serving to generate velocity and at the same time to absorb the resulting kinetic energy.

"IMPULSE-REACTION" TURBINES.

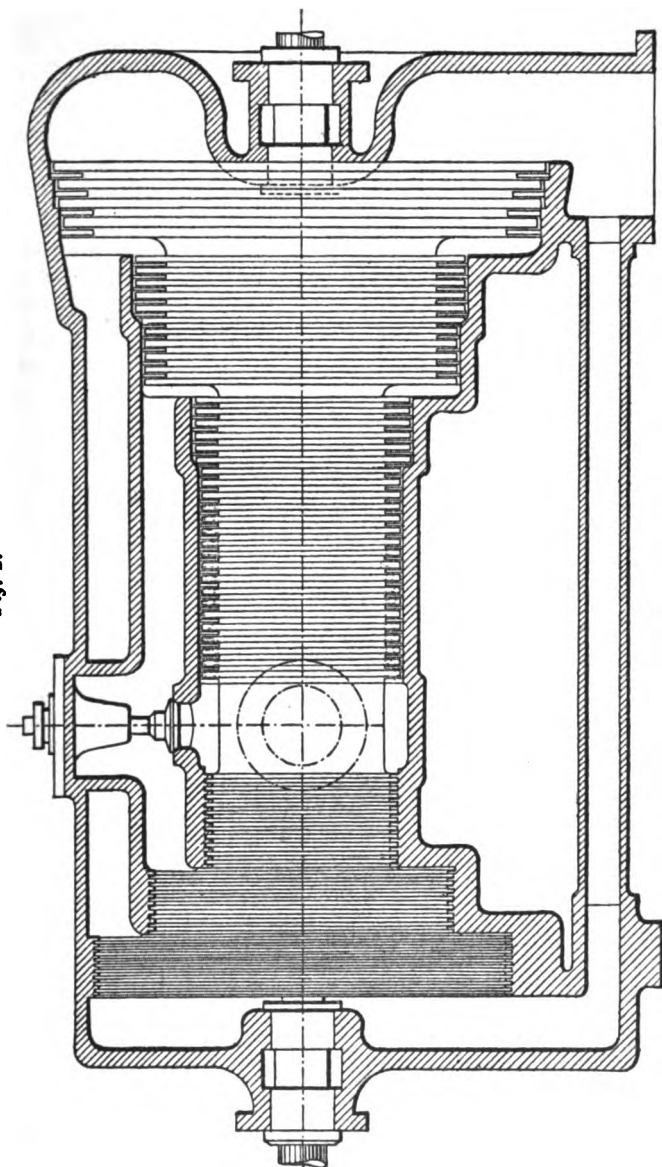
*The Parsons Turbine (Fig. 1).*²—A factor which influences the design of a steam-turbine probably more than any other is the high speed which the rotor must maintain in order to keep up the efficiency of the machine; this high speed is even more essential in the "impulse" type of turbine than in those of the "impulse-reaction" class. In the Parsons turbine the velocity of the steam

¹ Paper read and discussed before a meeting of the Manchester Association of Students of The Institution on the 21st February, 1906.

² The illustrations of this Paper being diagrammatic, no scales are affixed.

varies from about 200 feet per second at the admission end to

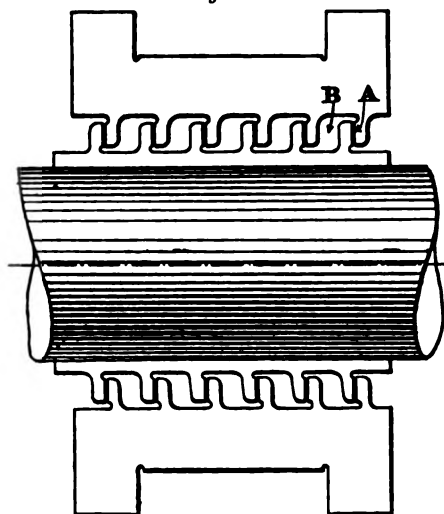
Fig. 1.



600 feet per second at the exhaust end, and, in consequence of the fact that for maximum efficiency the speed of the blades

should be about one-half the velocity of the steam, the large sizes of impulse-reaction turbines usually have a peripheral speed of about 300 feet per second at the exhaust end. The number of blades and the height of the blades both increase axially, i.e., in the direction of flow of the steam, in order to allow for the proper expansion of the steam as it passes through the turbine. Since expansion takes place in the rotating blades as well as in the stationary guide-blades, it is obvious that there will be a difference between the steam-pressures on the two sides of the former, and this difference will produce a pressure on the rotor in an axial direction. This axial pressure is neutralized by the pressure of the

Fig. 2.



steam on several "balancing pistons" which form part of the spindle, and are made steam-tight at their circumference on the "labyrinth" principle, by providing the least possible clearance combined with an excessively devious steam-path (Fig. 1). The same principle is employed in the design of the two stuffing boxes at the ends of the cylinder, where the shaft emerges from it (Fig. 2). The steam flowing through a narrow clearance, A, between the rotor and the stator, loses its velocity

in eddy-currents in a space, B, further removed from the cylinder. When this occurs a number of times, the drop in pressure due to expansion is very considerable, and thus very little steam, and that at a greatly reduced pressure, ultimately reaches the outside of the cylinder.

The bearings of the Parsons machine have been made the subject of special study; they must be sufficiently long to keep the pressure per square inch low, and yet not too long to prevent the shaft from "bedding in" along the whole length. The journal, again, must be of large diameter, in order to secure as rigid a shaft as possible, and yet not so large as to produce excessive friction at the periphery. The design of the bearings is therefore prescribed within fairly

narrow limits. For small machines a bearing is used which is built up of concentric brass sleeves fitting over one another with a clearance of a few thousandths of an inch all round. These clearance-spaces are filled with oil by capillary attraction, and any transverse motion is satisfactorily "damped" by the inertia of the oil. In large machines, however, which run at a comparatively low speed, solid bearings of cast iron, lined with white metal, have been found very satisfactory, and in order to provide for transverse motion the bearing is usually fitted into a spherical seating. Such bearings, if well supplied with oil, have a surprisingly long life; in the case of a 600-HP. Parsons turbine which ran continuously under load for 7,000 hours, the bearings did not require even to be scraped up. A most important point in this connection is a satisfactory oil-supply. This is easily obtainable with a good pump, the cost of which is soon repaid, owing to the fact that the oil may be used over and over again without any costly oil-separating devices, since in no case is the oil in contact with steam or water from any source, all metal-to-metal surfaces requiring oil being outside the cylinder. A coil in the return oil-pipe, immersed in a tank of cold water, is all that is necessary to secure cool bearings.

The rotor is usually balanced after the blades have been fixed on balancing-supports, after which it is put into temporary bearings and run up to speed by a powerful motor. The smallest want of balance is then noticeable, and may be corrected, on stopping the motor, by adjusting small weights on the drum. This procedure helps to secure immunity from blade-stripping disasters when the rotor is finally placed in its case. An accurate balance is essential, as the clearances between the rotating blades and the cylindrical case are only a few thousandths of an inch. The blades are usually cut from lengths of rolled brass of suitable section, and are fixed in slightly dovetailed grooves in the drum and cylinder alternately, with dovetailed distance-pieces; the latter, being caulked tightly in position, firmly grip the blades themselves. The rotor body calls for special care in design in order to secure a perfect balance. The built-up type of rotor is preferable, as all parts can be turned, inside and outside; and further, a solid cast-steel rotor might lack homogeneity. In the most modern type, nickel-steel ends holding the shaft are shrunk into a forged-steel drum or ring, turned inside and outside. The cylinder body also requires careful designing, for as the diameters increase, the tendency to distortion due to high temperatures also increases. No support must be given between bearings, or distortion due to unequal expansion is sure to occur, and the blades will be stripped. Any

stiffening-ribs which are cast on the cylinder must be perfectly symmetrical.

Various forms of valves and governing-gear are applied to turbines of this class, but since few published tests have as yet been made on these important details, it would be invidious to compare the different designs.

The Westinghouse-Parsons Turbine.—In the Westinghouse-Parsons turbine, some radical variations in design are noticeable. By admitting live steam at the centre of the machine and expanding it through an equal number of rows of blades on each side of the centre-line of the turbine, end-thrust and the necessity for balance pistons are done away with. Unless special provision were made however, the over-all length would be far too great for satisfactory working with superheated steam, on account of the distortion of the cylinder; and further, the initial blade height would be only half that for a "single-flow" machine. These difficulties are surmounted by allowing the expansion from boiler-pressure to about 60 lbs. per square inch absolute to be dealt with by two rows of impulse-blades fixed in the same drum as the reaction-blades. The loss of efficiency in these two rows, due to the skin-friction caused by the high velocity of the steam, is balanced by the leakage losses which occur in the very long high-pressure end of an ordinary Parsons machine of the same horse-power, in which a drum of small diameter, involving considerable length, is necessary, in order to make the height of the blades sufficiently great to give the best efficiency. The larger diameter of the Westinghouse-Parsons turbine carries with it a number of other practical advantages.

IMPULSE TURBINES.

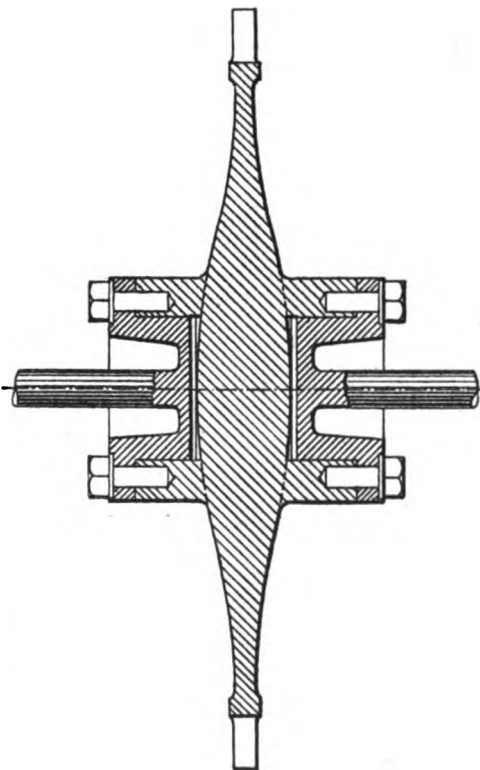
The De Laval Turbines.—The most important example of the "action" or "impulse" turbine is that of De Laval. In this turbine the steam is fully expanded in conical nozzles, thereby attaining a high velocity, after which it impinges on a single row of specially-constructed blades, fixed into the rim of a disk capable of rotation at an exceedingly high velocity. This velocity necessitates the use of gearing, usually in the ratio of 10 to 1, in order to reduce the speed to within reasonable driving-power limits. When steam is expanded adiabatically, in a properly-shaped nozzle from a pressure of 200 lbs. per square inch down to a vacuum of 28 inches of mercury, the velocity of the steam at the lower pressure is theoretically more than 4,000 feet per second. As much as possible of the kinetic energy thus generated should be used in the

vaness of the disk, and in order to accomplish this the steam must leave the blades at the lowest possible velocity. With the nozzles set at an angle of 20° to the plane of the wheel, the best result is obtained when the blades travel at a velocity which is 47 per cent. of that of the steam. The steam will then leave the vanes at about 34 per cent. of its initial velocity. Hence the velocity-efficiency of the turbine may be calculated, since the kinetic energy of the steam is proportional to the square of the velocity. Thus—

$$\frac{(\text{Initial velocity})^2 - (\text{Final velocity})^2}{(\text{Initial velocity})^2} = \frac{1 - (0.34)^2}{1} = 88 \text{ per cent.}$$

The best theoretical speed for any wheel may be calculated; for instance, with steam at an initial pressure of 200 lbs. per square inch absolute exhausting into a vacuum of 28 inches of mercury, the most efficient speed for the wheel is found to be 1,940 feet per second, or more than 22 miles per minute. Such high speeds are only permissible with wheels the cost of which would be prohibitive. The wheels at present in use are of forged nickel-steel of high tenacity, to withstand the great centrifugal forces at high speeds. They are solid throughout, tapering towards the circumference, and in the best practice the shaft is bolted on at each side by means of flanges, as shown in *Fig. 3*, as any hole through the disk is a source of weakness.

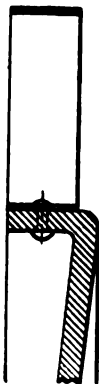
Fig. 3.



The gear-wheels have double helical teeth, and in large sizes, two sets of wheels are used, one on either side of the shaft, a

construction which preserves the latter from undue side pressure. The shaft is of very small diameter, the object being, not to

Fig. 4.

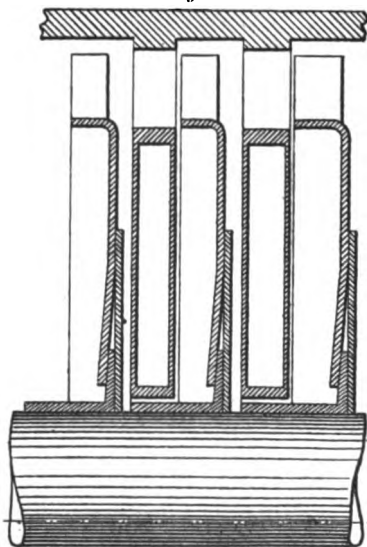


make the rotor revolve as steadily as possible about its geometrical centre, as in the Parsons type of turbine, but to allow the shaft to "whip" to some extent; so that the "critical" speed of the wheel may be considerably exceeded, when the vibrations due to the flexibility of the shaft will disappear, owing to the fact that the shaft then allows the wheel to rotate about its centre of gravity. Governing is effected by means of a double-seated valve connected by a steam-tight spindle and lever to a spring ball-governor through gearing driven by the shaft. The turbine gives very satisfactory results up to 300 HP. It can be started in a moment, and no difficulty is experienced with condensed steam in the pipes, as this is soon passed through the vanes. Moreover, the specially fine clearances necessary in reaction-turbines are not required, since

the pressures on each side of the vanes are the same.

The Rateau Turbine.—A second example of the "impulse" group

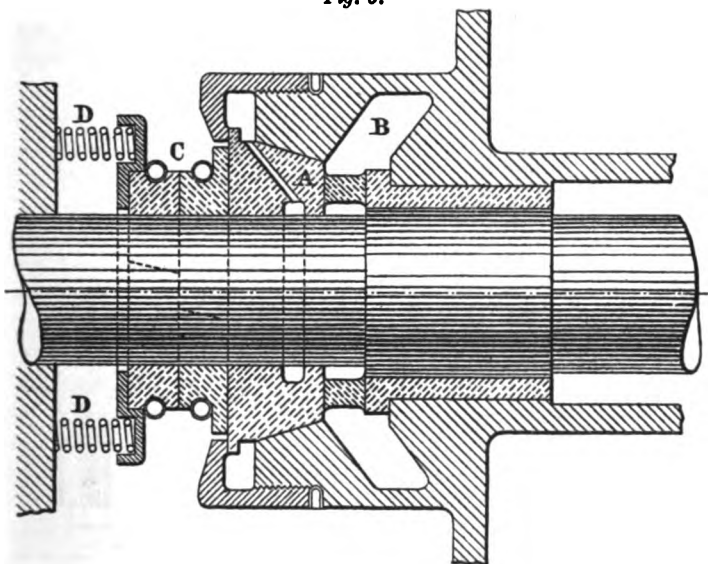
Fig. 5.



of turbines is the machine invented by Professor Rateau. It is in principle a multiple De Laval turbine, but owing to the expansion of the steam taking place in stages a much lower speed of rotation may be employed with efficiency. The advantages of stage-expansion are also obtained without the fine radial clearances necessary in a multiple-stage Parsons turbine. The Rateau cylinder is divided along the axial line, allowing the top cover to be lifted off. Each wheel is enclosed in a separate chamber, the nozzles, or more correctly, the guide-vanes, being set in the walls which separate two consecutive wheels. The wheels themselves are formed

of thin sheet plates pressed to a slightly conical shape, a steel band being welded on to the disk at the periphery; to this band

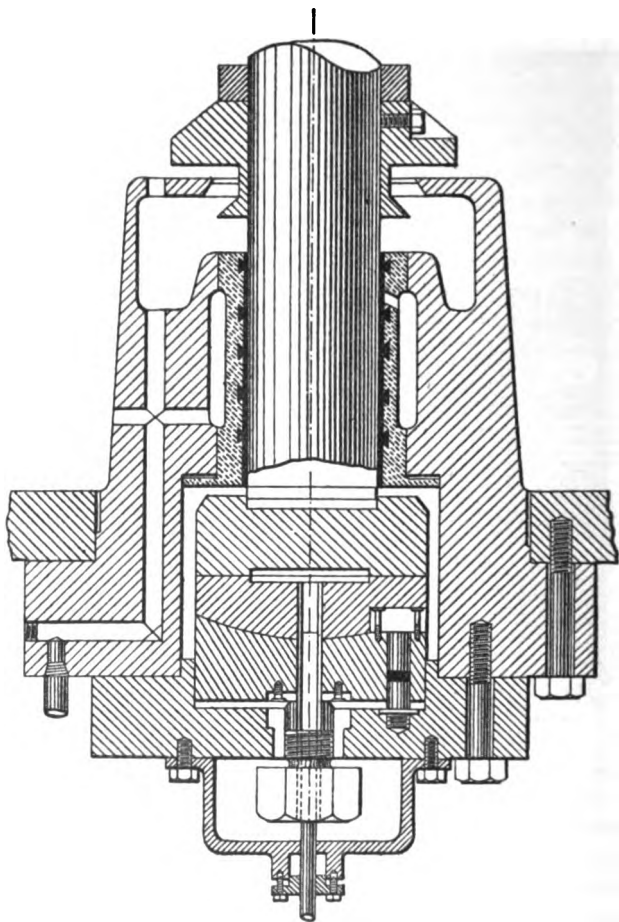
are riveted the blades, formed from pieces of bronze or steel plate bent to suit the curve of the band (*Fig. 4*). Each wheel, with its row of blades, is fixed separately on the shaft, whilst the intermediate walls or diaphragms, pierced by the guide-vanes, are fixed into the cylinder-casing and reach down to the shaft (*Fig. 5*), where a clearance of 3 millimetres (nearly $\frac{1}{8}$ inch) is allowed, since the leakage here has very little effect on the efficiency. These diaphragms act as stiffening-ribs to the cylinder. The over-all length of the machine as originally constructed was considerable, and the consequent distortion-troubles have now been obviated by the use

Fig. 6.

of two distinct cylinders and a central bearing. The wheels of the different expansion-stages increase in diameter towards the low-pressure end of the cylinder. The stuffing-boxes used by Professor Rateau are of somewhat novel construction (*Fig. 6*). The shaft is surrounded by a close-fitting box or sleeve, A, and steam leaking past this sleeve along the shaft is received in a chamber, B, formed in the cylinder-casing, and provided with a reducing-valve. Any steam blowing off through the valve is either condensed, or is carried away to the stuffing-box at the low-pressure end of the cylinder, where it serves to prevent the air from being sucked in. Two bronze rings, C, side by side on the shaft, are kept up to the face of the chamber by horizontal spiral springs, D, and effectually prevent

leakage to the atmosphere. This turbine is found to be particularly efficient when using very low-pressure steam ; good efficiency may be obtained even when using live steam below atmospheric pressure, and consequently in many large power-stations the exhaust-pipes of

Fig. 7.



the reciprocating-engine plant have been coupled to a Rateau turbine with most beneficial results.

The Curtis Turbine.—The Curtis turbine is another example of a multiple turbine of the "impulse" class. The turbine is built on a vertical axis, and the makers claim for it the advantages of compactness and absence of friction. When used to drive an electric

generator, the generator is placed vertically above the turbine on the same shaft. The footstep bearing is the weak point in such a construction. Cast-iron friction-plates are attached to the shaft-end and the footplate, and the weight is supported by fluid pressure, water being now used in place of oil for this purpose (*Fig. 7*). A cast-iron protection-plate is fitted on one of the wheel-disks, so that it would come down on to a flange of the cylinder in the event of a failure of the pump supplying the footstep-bearing with water. An auxiliary pump is, however, also provided, which comes into action the moment the first pump fails. In the Author's opinion, the vertical construction is open to the following objections:—

(1) A footstep-bearing is a source of uncertainty in any machine; moreover, the cost of the auxiliary machinery required for emergency purposes constitutes an addition to the prime cost of the machine.

(2) An electric generator on a vertical turbine-shaft is too much exposed to the risk of damage by steam leaking from the glands, or oil from the top generator-bearing, or by the heat from the body of the turbine below.

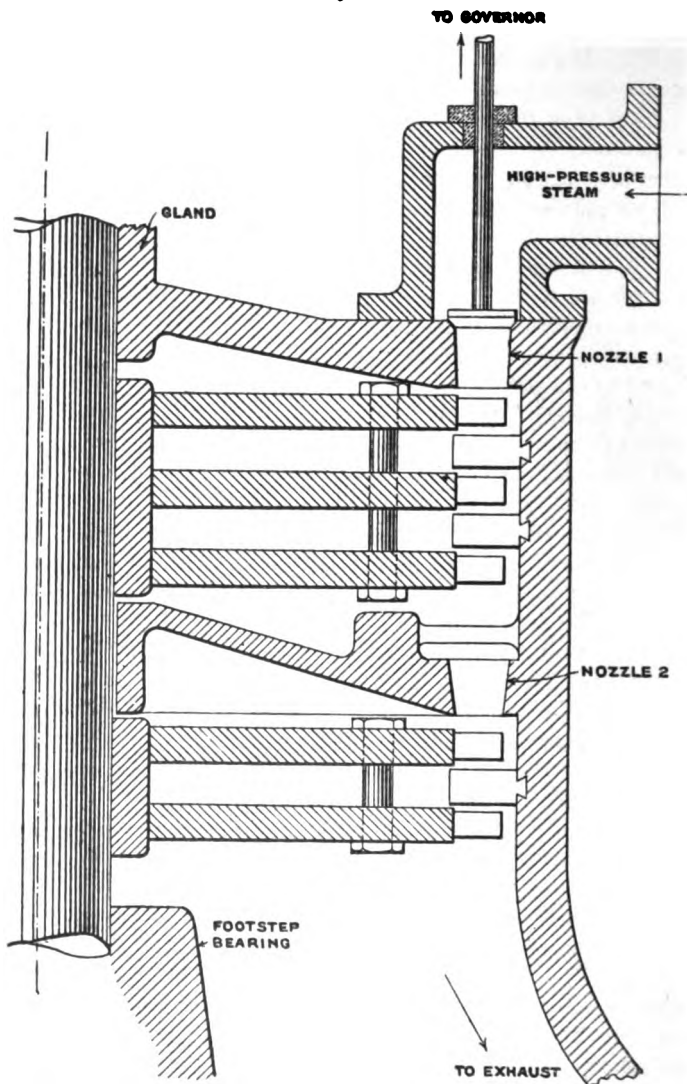
(3) The machine, if built horizontally, would be much shorter in over-all length than a corresponding Parsons turbine, so that the claim of the elimination of sagging tendencies in the rotor has not much weight.

The Curtis turbine was originally a four-stage De Laval turbine. The steam was expanded in the nozzles to a velocity of 2,000 feet per second, and the resulting kinetic energy was utilized in successive rows of blades, a portion in each row; the steam was then further expanded in a second set of nozzles, and the newly-developed velocity energy was dealt with by a second series of blades and vanes (*Fig. 8*). This process was repeated until the steam reached condenser-pressure.

It is interesting to note that the Rateau turbine possesses the advantage over the Curtis turbine that it runs with a lower steam-velocity and consequently with less skin-friction, but on the other hand, the wheel-friction in the Curtis type is decreased by combining three or four wheels, all rotating in steam of the same density; whereas in the Rateau machine each wheel rotates in steam at a different pressure, and the aggregate skin-friction is considerably greater for the same total drop of pressure. The Curtis turbine is governed by a centrifugal governor fixed on the top end of the shaft, and connected by levers and rods to an electrical controller, which in turn operates valves controlling the steam for each of the first stage of nozzles.

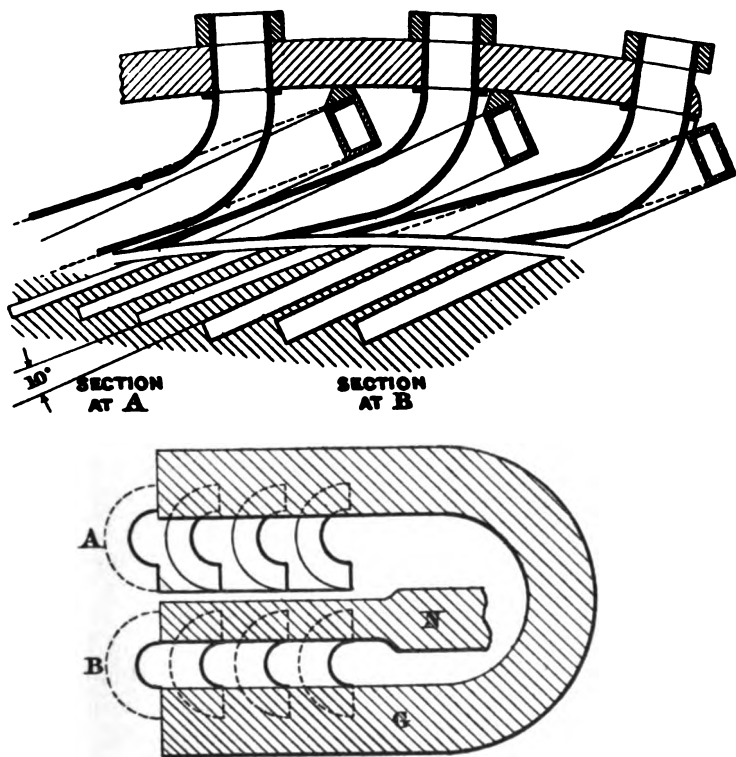
The Riedler-Stumpf Turbine.—This machine takes the form of one or more large wheels each in a separate chamber, with two or three other

Fig. 8.



wheels on the same shaft. The steam is fully expanded in nozzles, and after leaving the first large wheel is carried round in a semi-

circle through nozzle-piping to the other wheels (*Fig. 9*). The buckets are set almost tangentially to the wheels, and present the appearance of roofing-slates (*Fig. 10*). For maximum efficiency the angle of the secondary admission-blades must be more obtuse than that of the primary admission-blades, and this compels the makers to adopt a twisted form of nozzle-guide. In another construction the steam-jet is directed against the sharp edge separating two buckets on the

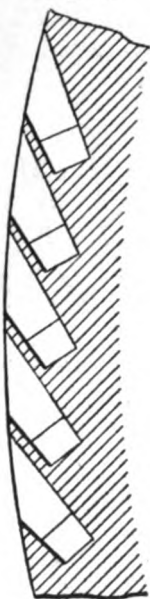
Figs. 9.

same wheel (*Fig. 11*). Each bucket receives half the jet, and the exhaust-steam is received at the sides of the wheel and carried through piping to a point further round the wheel, where it is again delivered as a combined jet.

The Zoelly Steam-Turbine.—This turbine is usually designed as a two-cylinder machine with a central bearing. Steam is expanded in each stationary guide, the machine differing in this particular from the Curtis design, which in other respects it resembles. This

construction increases the length of the turbine considerably for any given expansion, by increasing the number of rotating blades. The accuracy of finish and setting of the blades is a special feature of the Zöelley turbine. The blades are bent from steel plate, and are cut with lugs at the top and bottom which fit into grooves in the wheel; rings are fitted over these lugs and secured to the wheel, thus effectually preventing any alteration of the angle of the blades.

Fig. 10.

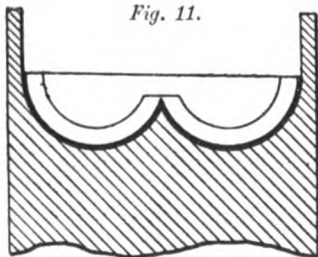


The Schulz Turbine.—In this turbine the steam enters at the centre and travels towards one end through a series of blades and guides, and is then carried back in a pipe to the centre, whence it traverses a similar series of blades and guides towards the other end. This is one of the few machines in which an attempt is made to govern by alteration of the section of the guide-channels; the alteration is made on the slide-valve principle by means of a loose ring with ports cut in it sliding over the entrance to the first set of guide-passages, and capable of being moved from outside the turbine-casing. The turbine is also fitted with a set of reversing-blades fixed at the exhaust end of the machine, and acting as a radial turbine. A point worthy of notice in the Schulz construction is the saw-tooth profile of the cylinder, at

points of small clearance, which is said materially to diminish leakage.

More recent machines, such as those of Lindmark, Gelpke-Kugel and others, might be described, but these have as yet scarcely emerged from the region of experi-

Fig. 11.



ment. The application of turbines to marine propulsion, also, is occupying the attention of many engineers at the present time, but the subject is too large to be adequately treated within the scope of this Paper.

The importance of obtaining a high vacuum in the condenser of a steam-turbine is so great, that there is no advantage in installing

turbines if a vacuum of more than 25 inches of mercury cannot be obtained. In the reciprocating engine, the value of a high vacuum is partly neutralized by the extra condensation in the

cylinder, due, of course, to the lower temperature of the exhaust steam ; and again, the steam cannot be expanded down to condenser-pressure without increasing the size of the cylinder to such an extent as to lose in mechanical friction what is gained by the better vacuum. In the turbine, however, although the space for expansion is fixed in size, the rate of outflow of the steam may be enormously increased. The skin-friction of the wheel is also materially lessened if the latter revolves in a medium of lower density, since the skin-friction is directly proportional to the density of the medium. A saving of, approximately, from 4 per cent. to 5 per cent. in economy may be obtained for each inch of vacuum in excess of 25 inches.

Among the advantages of the steam-turbine over the reciprocating engine, the Author considers the following to be the most important:—

- (1) It is cheaper to build than a reciprocating engine of the same power.
- (2) It occupies less space.
- (3) It causes less vibration and requires lighter foundations.
- (4) The cost of upkeep and attendance is lower.
- (5) It gives a perfectly even turning-moment, making it an ideal prime mover for a steady electrical load.
- (6) It requires no internal lubrication ; consequently the steam is kept perfectly clean and is ready to be returned to the boiler immediately on leaving the condenser.
- (7) It is no less economical than the highest class of reciprocating engine.
- (8) The steam may be given a high degree of superheat, with consequent economy.
- (9) Owing to the absence of rubbing surfaces its life is long.
- (10) It is more accessible than a reciprocating engine.

In the Author's opinion, however, the reciprocating engine, for many years to come, is sure to maintain its position under certain circumstances. The possibility of starting it against full load and of reversing it economically, at once ensure for it a sphere of usefulness which at present the steam-turbine cannot invade.

The Paper is accompanied by six drawings, from which the Figures in the text have been prepared.

OBITUARY.

IMRIE BELL, born at Edinburgh in 1836, was educated at Edinburgh High School, and served his apprenticeship with Messrs. Bell and Miller, of Glasgow. After acting as Resident Engineer on the construction of the Meadowside graving-dock for Messrs. Tod and McGregor, of Glasgow, he entered the service of the East Indian Railway Company in 1859, and, proceeding to India, was appointed Resident-Engineer on the southern half of the large railway bridge over the Jumna at Allahabad. The plan adopted for sinking the foundations of this bridge on wells was described by him in a communication to The Institution in 1868, for which he was awarded a Telford premium.¹ On the completion of the work in 1865, he joined the staff of the late Mr. Thomas Brassey, for whom he took charge, as contractor's engineer, of the erection of the Sirsawa bridge over the Jumna.

Returning to Scotland in 1869, he was appointed in the following year Superintendent and Engineer of the Leith docks and harbour. In 1872, on the nomination of the late Sir John Coode, Past-President, he became Executive Engineer for the construction of St. Helier's harbour works and breakwater and La Corbière lighthouse. An account of the latter interesting work was presented by Mr. Bell to The Institution in 1879.² He joined the firm of Bell and Miller at their Westminster office in 1878, removing subsequently to Glasgow, and on the death of Mr. Daniel Miller he became sole partner. Retiring from business in 1898, he went to live at Croydon, where, after a short illness, he died on the 21st November, 1906, aged 70.

Mr. Bell was elected an Associate of The Institution on the 21st May, 1867, and was transferred to the class of Members on the 21st April, 1868.

¹ Minutes of Proceedings Inst. C.E., vol. xxviii, p. 325.

² *Ibid*, vol. lix, p. 217.

CARL RODERIQUE LOUIS MENNI BONN, son of the late Dr. L. M. Bonn, of Brighton and Taunton, was born in 1858 and received his education at Taunton College. After serving a pupilage to Mr. J. H. Smith, Borough Engineer of Taunton, he obtained employment under Sir John Wolfe Barry, Past-President, and the late Mr. H. M. Brunel, and remained in their service 13 years, from 1877 to 1890, during which time he was engaged on the Lewes and East Grinstead Railway, Blackfriars bridge and St. Paul's station, the Metropolitan and Metropolitan District systems, Barry docks and railway, and many other works. Between 1890 and 1897 he acted as Resident Engineer for Messrs. Formans and McCall on the West Highland Railway, the Lanarkshire and Dumbarton line, Bowling harbour improvements and other works, and was associated with that firm and with Sir John Wolfe Barry in the preparation of drawings and designs for the Glasgow Central Railway and in parliamentary studies for the Kilpatrick and Renfrew dock schemes.

In 1897 Mr. Bonn engaged in consulting practice in Glasgow in partnership with Mr. John Taylor Babbie, and the firm of Babbie and Bonn was responsible for many important engineering enterprises, including the structural work for the Glasgow Exhibition of 1901, and waterworks for Dumbarton, Helensburgh, Bowling, Kilpatrick and the Vale of Leven. Mr. Bonn died very suddenly on the 19th October, 1906, whilst on a visit of inspection to waterworks under construction by his firm for the district of Old Kilpatrick.

He was elected an Associate Member of The Institution on the 5th February, 1884, and was transferred to the class of Members on the 16th November, 1896.

ALEXANDER DUNCANSON was born in 1819, near Dunfermline in Fifeshire, and served his apprenticeship with Messrs. Caird and Company, Shipbuilders, of Greenock. In 1845 he entered the service of the Bootle Waterworks Company, which, with the Liverpool and Harrington Company, at that time supplied Liverpool with water. Whilst in their service, Mr. Duncanson rendered valuable assistance to the company's engineer, the late Mr. Michael Scott, in connection with improvements in the pumping machinery, which resulted in a considerable saving being effected. In 1848 the water companies were taken over by the Liverpool Corporation, to whom Mr. Duncanson transferred his services, acting as Assistant Engineer

under the late Mr. Thomas Duncan until that gentleman's death in 1869. During that period Mr. Duncanson had charge of the pumping stations and machinery, and superintended the sinking of a new well and the construction of an engine-house at Bootle. He also carried out a series of experiments on the yield of wells at Rivington for the late Mr. Robert Stephenson, Past-President. In 1869 he became acting Water Engineer, and had sole management of the waterworks until 1872, when Mr. G. F. Deacon was appointed Borough and Water Engineer. Mr. Duncanson also held charge of the public baths and wash-houses of Liverpool, and was responsible for the design and construction of four large establishments. In 1881 Mr. Deacon devoted himself entirely to the work of carrying out the Vyrnwy water-supply, and Mr. Duncanson as Deputy Water Engineer became responsible for the home work. This arrangement continued until 1890, when failing health necessitated his relinquishing part of his duties, and in the following year he definitely retired from professional pursuits at the age of 71, having been in the service of the Corporation for 43 years. Although essentially a practical man, a type of the engineer whose shrewd common-sense contributed largely to the advancement of engineering during the past century, the scientific side of his profession always held a deep attraction for Mr. Duncanson. He made some valuable researches on the flow of water in pipes, and was one of the first to advocate the systematic flushing of sewers and drains. For several years Mr. Duncanson held a commission in the 2nd Lancashire Engineer Volunteers. He died at Liverpool on the 20th January, 1906, at the advanced age of 86.

He was elected a Member of The Institution on the 7th March, 1876.

JOHN DEVONSHIRE ELLIS died at his residence, Sparken, Workson, on the 11th November, 1906, in his eighty-third year. Born on the 20th April, 1824, he was the son of Charles Ellis, a Birmingham engineer, and as a young man he entered his father's works in that city, where he gained a thorough practical knowledge of the manufacture and working of brass and other metals. In 1848 he and his brother were taken into partnership, the firm becoming Charles Ellis and Sons.

The co-partnership formed in 1854 between Mr. (afterwards Sir) John Brown, Mr. John Devonshire Ellis, and Mr. William Bragge had far-reaching results. At the outset of its career, the business was of

modest dimensions, the Atlas Works purchased by the partners being only 3 acres in extent, while the output of iron in the early years was seldom over 5,000 tons. Soon after the organization of the company, however, the question of providing armour for British ships came to the fore, owing to its application in 1858 to the French warship "La Gloire." Messrs. Brown and Ellis at once set themselves to evolve a more economical and expeditious system of manufacturing armour-plates than that adopted by the French, which was successfully accomplished by processes of welding and rolling, and the first armour-plates produced by this method were fitted to the "Black Prince" and "Warrior." The thickness of the plates, at first 4 inches, was continually increased to meet improvements in guns and projectiles. As the partner responsible for the practical management of the engineering and manufacturing departments of the works as well as of the firm's collieries, Mr. Ellis had to devise improved appliances for the thicker armour, and this for several years gave full scope to his energies. Like others engaged in metallurgy, Mr. Ellis found the contest between armour and artillery very fascinating. Steel armour had been tried, because of its greater resisting power than wrought iron, but it was found that the steel plate lacked toughness, and fell to pieces under the impact of the shot. Mr. Ellis then concentrated his attention upon the welding of a hard steel plate upon a wrought-iron backing, so that, while the face of the steel resisted perforation, the backing gave the required tenacity to hold the plate intact. After many experiments he succeeded in uniting the two plates by a patented process, designed to ensure a perfect weld. He then took up the problem of the cementation of the armour, at which he worked from 1871, when he took out his first patent, and had his first plate tried, until success was finally reached in the satisfactory trials of the first chilled compound plate of the Ellis-Tresidder type at Shoeburyness in 1891.

The enterprise which he displayed in connection with the early application and advocacy of the Bessemer process was characteristic. Bessemer's works closely adjoined the Atlas establishment, and Mr. Ellis being thus afforded an early opportunity of becoming acquainted with the new process, his investigation resulted in the instalment at the Atlas works of the first working apparatus on the new system to be put in operation in this country outside Bessemer's works. For his early recognition of the process and for his work in connection with armour-plates, Mr. Ellis was awarded the Bessemer gold medal of the Iron and Steel Institute in 1889.

Mr. Ellis conducted much research work at the Atlas Works, and his name is associated with a form of induced draught with which

successful results have been achieved, and by which the smoke nuisance has been somewhat abated. He found an outlet for his mechanical ability also in the improvement of the workshop plant of the works, and he devised a mill for rolling the ribbed boiler-flues of the Purves and "camber" types, and also in connection with the manufacture of Serve tubes.

After the retirement of Sir John Brown in 1870, and the death of Mr. Bragge, the other original partner, in 1884, Mr. Ellis was left in sole charge of affairs. The partnership was formed into a limited liability company in 1864, and Mr. Ellis became managing director, a position which he held for about 35 years. During that period many developments took place and considerable additions were made to the establishment. In 1899 the famous Clydebank Ship-building and Engineering Works were acquired. The Atlas Works at the date of Mr. Ellis's death covered an area twelve times greater than when they were first started; and the output of steel for various purposes increased to about 100,000 tons per annum.

Some years before his death, Mr. Ellis was presented by the King of Sweden and Norway with the Order of the Wasa. He was of a retiring disposition, and took little part in the public life of Sheffield, although he sat as a magistrate for the West Riding of the County of York, and was a Member of the Cutlers' Company for many years. He was one of the original members and a Vice-President of the Iron and Steel Institute. He was always a good companion and an excellent *raconteur*, especially in connection with the early difficulties of the metallurgical industry.

Mr. Ellis was elected a Member of The Institution on the 8th January, 1884.

RICHARD GERVASE ELWES was educated for the engineering profession at King's College, London, and entered the Public Works Department of India in 1860 as an Assistant Engineer. After 14 years' service, he retired on account of ill-health in 1874, with the rank of Executive Engineer, second grade. The works upon which Mr. Elwes was engaged in India comprised sections of the Hindustan and Tibet and the Kooloo and Ladak roads, the Koksar bridge and large bridges on the Grand Trunk road near Umballa, the water-supply of Umballa, and the Sirhind canal. He also acted for short periods as an Assistant Secretary and as Secretary for Public Works, Hyderabad.

Between 1877 and 1890, Mr. Elwes engaged in consulting practice in London in partnership with the late Mr. G. Wells Owen, and during this period the firm carried out, amongst other works, the Bury and Tothington district railway, the Hounslow line, the Golden Valley railway extension to Hay, the Bridgwater railway and an extension of the Winnipeg waterworks.

In 1893 Mr. Elwes went to Spain on behalf of Messrs. Matheson and Company, in connection with the Zafra-Huelva railway and to take charge of mines, marble quarries and other works; and on his return in the following year he took an office in the city and became interested in mining matters, especially in copper mines, either as consulting engineer or as a director. He died on the 14th August, 1906.

Mr. Elwes was elected an Associate of The Institution on the 6th May, 1873, and was transferred to the class of Members on the 9th April, 1878.

WILLIAM SILVER HALL, son of the late Mr. William Hall, of Atherstone, was born on the 17th June, 1844, and received his later education at Repton School and Brighton College. After serving an apprenticeship of 3 years to Messrs. Sharp, Stewart and Company, of Manchester, he fulfilled several engagements with mechanical engineering firms, and thus equipped with experience, he engaged in 1874 in mechanical engineering and consulting practice at Nuneaton, being joined later by Mr. Charles D. West. A few years earlier he had gained a Whitworth exhibition and a Whitworth scholarship tenable for 3 years. In 1880, in consequence of Mr. West's ill-health, the business was disposed of, and soon after Mr. Hall joined Mr. J. H. Clarke in carrying on the business of the Canal Street Ironworks, Derby.

In August, 1889, Mr. Hall left this country for Japan, where he spent the remainder of his life. He occupied for a time the chair of engineering in Tokyo University, and he also acted for some years for Messrs. Takata and Company, who were one of the largest firms in Japan engaged in important Government contracts and the importation and erection of engineering machinery and appliances. Mr. Hall early in his career interested himself in the subject of patents and patent law in general, of which he had acquired expert knowledge, and whilst acting as correspondent to *The Engineer* in Japan, he was the means of assisting many persons to get their patents through the Japanese courts. Finding scope

for development in this direction, he left Messrs. Takata and Company, and started in independent practice as a patent agent in Tokyo. His accurate knowledge and engineering experience brought him a considerable measure of success, and in course of time he acquired a practical monopoly of this business in Japan. He died on the 26th July, 1906, aged 62. He was the Author of a "Manual of the Japanese Laws and Rules relating to Patents, etc.," published in 1901, and contributed numerous articles on engineering subjects to the technical press. He was a Member of the Institution of Mechanical Engineers. In Japan, he was a prominent and active Freemason and served several terms of office as Worshipful Master of the Tokyo Lodge.

Mr. Hall was elected an Associate Member of The Institution on the 3rd February, 1885, and was transferred to the class of Members on the 29th March, 1897.

FRANCIS JOSEPH LYNCH obtained his early engineering training under the late Mr. P. Prichard Baly on the construction of railways and canals in Belgium and in Russian Transcaucasia. For a short period subsequently, he acted as Resident Engineer on the construction of the Poti-Tiflis railway, but was obliged to leave for home in 1865 in consequence of ill-health. He then decided to follow his profession in Canada, and arriving in that country in 1869, he obtained employment as Engineer in charge of surveys for the Intercolonial Railway, subsequently acting as Resident Engineer on the construction of a section of that line. On the completion of this work, Mr. Lynch joined the staff of the Canadian Pacific Railway, then under construction, his wide experience of railway work rendering him a welcome recruit to the ranks of the energetic and capable body of engineers who were responsible for the successful completion of that great enterprise. During the latter part of the work, and for some years afterwards, Mr. Lynch held charge of the chief office at Ottawa under the Deputy Minister of Railways and Canals. For 5 years prior to his death he acted as Resident Engineer on the Grenville and Ottawa Canal. He died at Ottawa on the 5th January, 1906, from pneumonia, following upon a severe cold contracted whilst engaged upon his work on the canal.

Mr. Lynch was elected a Member of The Institution on the 6th December, 1881.

WILLIAM PRIME MARSHALL, who died at Edgbaston on the 27th March, 1906, at the advanced age of 89, was the only son of the Rev. William Marshall, of St. Albans. Born in 1816, the subject of this notice received an excellent education from his father, supplemented by attendance at King's College, London, and entered the office of Mr. Robert Stephenson in 1835, where he was employed on the working drawings for the London and Birmingham Railway. In 1839 he carried out for Mr. Stephenson the design and construction of stations on the North Midland Railway, and on the opening of that line, he was appointed locomotive superintendent, which office he held until the amalgamation of the line in 1843 with the present Midland Railway. In the following year, he carried out, in conjunction with the late Sir George (then Mr.) Berkley, a series of experiments in connection with the Dublin and Kingstown atmospheric railway, and subsequently, the alteration of the gauge of the Eastern Counties Railway. Later, on the recommendation of Mr. Stephenson, Mr. Marshall was appointed locomotive engineer of the Norfolk Railway.

In 1848 Mr. Marshall engaged in consulting practice at Birmingham. In the following year, on the nomination of Mr. Robert Stephenson, he was appointed Secretary of the Institution of Mechanical Engineers and held this office until the removal of the society to London, a period of 29 years, at the same time carrying on private practice. During this period, he was engaged on various special investigations and reports; amongst others, for the London and North Western Railway, on the working of locomotives between London and Rugby, and for the East Indian and Madras Railways, on the manufacture of springs for the rolling stock of those railways. He also undertook inspection of materials for the same companies at the principal engineering works in the provinces, and this work led to his being extensively employed in a similar capacity by the Crown agents for the Colonies. After his retirement from the secretaryship of the Institution of Mechanical Engineers in 1877, Mr. Marshall continued his inspection and other work in partnership with his son, Mr. W. Bayley Marshall, until 1904. Mr. Marshall was a member of various local societies at Birmingham, and he also took part in the formation of the Birmingham and Midland Institute. In 1898 he contributed to the Proceedings of The Institution a Paper on "The Evolution of the Locomotive Engine,"¹ for which

¹ Minutes of Proceedings Inst. C.E., vol. cxxxi, p. 241.

he was awarded the George Stephenson medal and a Telford premium.

Mr. Marshall was elected an Associate of The Institution on the 3rd June, 1845, and was transferred to the class of Members on the 10th April, 1866.

VITALE DOMENICO DE MICHELE, fourth son of the late Mr. Eastland de Michele, for many years British Consul at St. Petersburg, was born in London on the 11th November, 1848. He was educated at Westminster School, and manifesting a decided bent towards mechanical engineering, he was apprenticed at an early age to Messrs. Robert Stephenson and Company, of Newcastle-on-Tyne. He took a deep interest in his work and whilst at Newcastle he invented a new form of reversing gear for locomotives and marine engines. Before the expiration of his pupilage, he was selected to take charge of the extensive exhibit of the firm at the Paris Exhibition of 1867.

In 1868 Mr. Eastland de Michele, having retired from the consular service, acquired a large interest in the business of Messrs. Francis and Company, cement manufacturers, of Vauxhall and Cliffe, Kent, and the senior partner dying about this time, Mr. Vitale de Michele took over the entire management of the cement works at Cliffe Creek. Subsequently he became a partner in the firm, and the association with cement manufacture thus begun lasted practically the whole of his life and was productive of many important contributions to the advancement of the industry. During his management of the Cliffe Creek works, which were rebuilt and enlarged by him, he introduced various improvements into the methods and machinery employed in cement manufacture, which he found comparatively crude and uneconomical. To Mr. Michele is due an improved form of wash-mill, special hydraulic pumps, designed in conjunction with the late Mr. Platt, of Gloucester, for pumping the slurry to the drying floors, and a new system of drying the slurry by waste heat from the kilns. These and other improvements effected by him resulted in shortening and cheapening the process of the manufacture of Portland cement, and in rendering the product more uniform and reliable. The cement-testing machine which he invented marked a great improvement on the old system and has been extensively adopted. He also took a great interest in smoke prevention, and designed a special grate which produced good results.

In 1877, whilst still controlling the works at Cliffe, he engaged in consulting practice at Delahay Street, Westminster, and carried out, amongst other works, wharves at Vauxhall and Greenhithe, water-supply works at Higham, the stiffening of the swing portion of Rochester bridge, drainage and embankment work at Strood, the erection of several cement factories, and the design and construction of steel screw triple-expansion steam-tugs and a number of steel lighters.

Mr. Michele contributed many articles on cement to the technical press. He was a regular attendant at ordinary meetings of The Institution and was also a Member of the Institution of Mechanical Engineers. Unswerving loyalty and a cheery and genial disposition brought him many friends, with whom he was deservedly popular. He died at his residence, Higham Hall, Rochester, on the 21st March, 1906, aged 57.

He was elected an Associate of The Institution on the 1st December, 1874, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 8th November, 1891.

ROBERT BELLECHASSE MORISON was born in London on the 26th August, 1865, and after completing his education at King's College, London, he served his apprenticeship to the late Mr. Alfred Rumball. In 1887 he went to South America as Assistant Engineer, and subsequently became Resident Engineer, on the South-Western Railway of Venezuela, where, with the exception of a short interval spent on irrigation work in California, he remained until 1895, when he went to South Africa. He was first employed on railway surveys and construction in the Orange River Colony, on the completion of which he joined the staff of the Cape Government Railways, and remained in the Government service until ill-health obliged him to leave South Africa. Between 1897 and 1905 he was employed in responsible positions on the Port Elizabeth and Avontuur railway survey, the construction of the Mashonaland railways, Transkeian and Concordia surveys, reduction of gradients on the Eastern lines, and the construction of various portions of the Cape railway system. During the war Mr. Morison bore his full share of the arduous and difficult work of repair and renewal of the railway rendered necessary by the operations of the combatants. He was last employed as Inspecting Engineer to the

Government on the Mossel Bay extension of the Cape Central Railway. He succumbed to the effects of a serious operation in the West Middlesex Hospital on the 29th January, 1906, aged 40.

Mr. Morison was elected a Member of The Institution on the 7th March, 1905.

JOHN PRICE, City Surveyor of Birmingham, died suddenly, after undergoing an operation, on the 6th March, 1906, at Burnham, Somerset. Born on the 22nd June, 1855, the subject of this notice was educated at the Manchester Grammar School and at the Owens College, Manchester, where he gained the Ashbury exhibition in Civil Engineering. With the exception of his first appointment, which was that of Engineer on the construction of the Hollinwood branch of the Lancashire and Yorkshire railway, Mr. Price's career was entirely devoted to the municipal branch of the profession. Between 1876 and 1878 he was employed as Resident Engineer on the Barrow-in-Furness main drainage works; for the next 6 years he occupied the position of Engineer and Surveyor to the Barton Sanitary Authority; and from 1884 to 1895 he acted as Engineer and Surveyor to the Toxteth Urban District Council. In the latter year, Toxteth being brought within the city boundaries of Liverpool, Mr. Price was appointed Assistant City Engineer.

In 1896 Mr. Price was selected to fill the office of City Surveyor of Birmingham in succession to the late Mr. W. S. Till. The first work of importance undertaken by Mr. Price at Birmingham was the reconstruction on modern principles of the sewerage of Edgbaston and Harborne, which he carried out with signal success. Throughout his tenure of office Mr. Price was continuously and closely occupied with the manifold duties attaching to the Surveyorship of a large and growing city. Considerable reorganization of the staff of his department was effected, and a number of important works were put in hand. Among these may be mentioned the reconstruction of a section of the Rea main sewer; the improvement and diversion of the River Rea, near Calthorpe Park; extensive wood paving; the construction of underground lavatories; the extension of Corporation Street; and the construction of Small Heath Viaduct. To these must be added the arrangements for relaying the old tramways for electrical traction, and the commencement of new lines. All these works, with others not enumerated, required much skill and attention, and were carried out to the complete satisfaction of the Corporation.

Mr. Price was a Fellow of the Surveyors' Institution, and was connected with various municipal societies. He also served the office of president of the Birmingham Association of Students of The Institution, taking great interest in the welfare of the younger members of the profession.

He was elected an Associate Member of The Institution on the 2nd December, 1879, and was transferred to the class of Members on the 7th December, 1897.

SIR EDWARD JAMES REED, K.C.B., F.R.S., died on the 30th November, 1906, in his seventy-seventh year. He was born at Sheerness in the year 1830, and commenced his practical training in the Royal Dockyard at that place. He afterwards passed through the School of Mathematics and Naval Construction in Portsmouth Dockyard, and next received a subordinate appointment at Sheerness. He left the Admiralty service in 1852, and became assistant editor of the *Mechanic's Magazine*. He was one of the most active promoters of the Institution of Naval Architects, which was founded in January, 1860, and acted as Secretary of that Institution during the first three years of its existence. In July, 1863, he was appointed Chief Constructor of the Navy. This appointment followed upon proposals he had made some time before for improving the design of ironclad ships. Sir Edward Reed proposed a radical change of design as compared with the earliest ironclads of the "Warrior" and "Minotaur" classes, limiting the armoured portion of the hull to what was merely sufficient for the proper protection of its vital parts, such as the compartments containing the boilers, machinery and magazines, the gun battery, the rudder-head and steering-gear, and the water-line area before and abaft the gun battery. This became well known as the "belt and battery" system, and is, in general principle, the system adopted in the design of battleships and armoured cruisers to-day. The wooden ships "Enterprise," "Favourite," and "Research" were ordered by the Admiralty to be converted in accordance with Sir Edward Reed's proposals in 1862, and the design of the "Bellerophon" followed immediately after he took office in 1863. The last-named was the first of a series of historical ships that led in direct line to the last British armour-clads which fought their guns upon the broadside; while the "Devastation," the last battleship designed at the Admiralty by Sir Edward Reed, is the first in the long list of sea-going battleships, the heaviest guns

of which are placed in revolving turrets on deck. The design of the structure of the hull in the "Bellerophon" was novel and ingenious, and it has been followed, in principle, in the later battleships and cruisers of the British Navy, and adopted all over the world.

Sir Edward Reed resigned the Chief-Constructorship of the Navy in July, 1870, and after leaving the Admiralty, he practised as a naval architect till his death. He designed some famous warships for the German, Japanese, Chilian and other foreign navies, notably the fast battleships, "Libertad" and "Constitucion" for the Chilian navy, which were purchased by the British Government while under construction, and are now known as the "Triumph" and "Swiftsure." He was also consulting naval architect to the Indian Government and to the Crown Colonies, and designed and superintended the construction of many vessels for those services.

He was always a strenuous advocate of scientific and technical education, and did much when Chief Constructor of the Navy to influence the Admiralty in establishing the Royal School of Naval Architecture and Marine Engineering at South Kensington in 1864, to which many of the leading naval architects and marine engineers of the present day owe their scientific training. It was also owing to his intelligent appreciation of the value of the late Mr. William Froude's early model-experiments upon the resistance and propulsion of ships, and his favourable recommendation to the Admiralty, that this method of estimating speed and power and of determining the most suitable forms of hull was first applied to the improvement of the ships of the Navy and that the invaluable services of Mr. Froude were obtained for this important work.

In 1873 Sir Edward (then Mr.) Reed contested unsuccessfully the Borough of Hull at a Parliamentary election. He was returned for the Pembroke Boroughs in 1874 and for Cardiff in 1880, and sat continuously in the House of Commons from 1874 to 1895, and from 1900 until 1905, when he retired from Parliamentary life. He was made a C.B. in 1868 and K.C.B. in 1880, and served as a member, and sometimes as chairman, of many important committees. He was chairman of the Load-line Committee of 1884, which first made legislation for regulating the depth of loading of ships successful in practice, and of the Manning of Ships Committee of 1894. He was also appointed Government Commissioner to investigate the cause of capsizing of the "Daphne" in the Clyde in 1883, and he was one of the Lords of the Treasury in Mr. Gladstone's Government of 1886.

Sir Edward Reed was elected a Fellow of the Royal Society in 1876. He served upon the council of the Institution of Naval

Architects from 1863, when he retired from the secretaryship, until his death. In 1885 he delivered before The Institution of Civil Engineers one of a special series of lectures, taking for his subject the "Forms of Ships." Among his published works are: "Ship-building in Iron and Steel," 1869; "Our Ironclad Ships," 1870; "The Stability of Ships," 1884, and "Modern Ships of War" (in collaboration with Admiral Simpson), 1885. He was also a frequent and valued contributor to the proceedings of the leading scientific and technical societies. He was the proprietor and editor of the quarterly magazine *Naval Science* from 1872 to 1875, and contributed many articles to its pages.

He was elected a Member of The Institution on the 1st March, 1870, and served on the Council from 1883 to 1896.

JAMES ROWAN, born in Glasgow on the 18th March, 1854, was the son of the late Mr. David Rowan, founder of the marine engineering firm of David Rowan and Company, of that city. The subject of this notice was educated at the Glasgow Academy and at Glasgow University, and subsequently served an apprenticeship of 5 years in his father's works. In 1880, when 26 years of age, he became Assistant Manager of the works, and 5 years later was made partner with his father. In 1888 he took over complete control of the business, of which he retained the active direction until his death. The dispute which arose in the engineering trade in 1897, and in which Mr. Rowan's firm was involved, directed his attention to economic questions, and led to his undertaking a thorough investigation into the methods and details of administration and the remuneration of labour. The result of his enquiry was a careful reorganization of the works in respect of equipment and methods of management, in which his organizing ability and sound practical common-sense found full scope. After a trial of the premium system of remuneration as originally devised, he set to work to eliminate the defects which in practice rendered that system unpopular with workmen, and the improved system, with which his name is associated, has since been widely adopted and developed. His Paper on works organization and the remuneration of labour, contributed to the Engineering Conference at Glasgow in 1901, attracted much attention at that gathering and evoked an interesting discussion.

In many organizations connected with engineering Mr. Rowan took

an active and useful part. When the rivet and nut makers of the west of Scotland combined, he was a strong advocate and an active promoter of the Federation works, which were conducted practically on the co-operative system. He was a Member and served on the council of the Institution of Mechanical Engineers; and was a Member of the Institution of Naval Architects and of the American Society of Mechanical Engineers. He was also a Member of the North East Coast Institution of Engineers and Shipbuilders; and a Member, some time Vice-President, and at the date of his death a Member of Council of the Institution of Engineers and Shipbuilders in Scotland. He died suddenly at his residence at Glasgow on the 19th November, 1906, in his fifty-third year.

Mr. Rowan was elected a Member of The Institution on the 6th December, 1898.

FREDERICK SHARP, born on the 22nd March, 1854, was the son of the late Mr. Samuel Sharp, of Tangleymere, Chilworth, Surrey. Entering the Royal Indian Engineering College, Coopers Hill, in 1872, he passed out 3 years later, and after a short period of practical training on the London and North-Western Railway, he left in October, 1875, for India, and was posted as Assistant Engineer to the Mysore Public Works Department. Mr. Sharp remained in India until 1887. His early experience was obtained on famine relief works in Mysore, and later he was employed on various public works in Mysore and Coorg, notably the erection of the Saddipur bridge over the Cauvery river in the latter province. In 1887 he went to Burma, where he was engaged as Executive Engineer on pioneer work with the troops, after the annexation of Upper Burma, and subsequently took part in the development of the country by the construction of roads, buildings and irrigation works. After 20 years' service in India and Burma Mr. Sharp retired with the rank of first grade Executive Engineer. Returning home in 1895 he became a partner in the firm of Messrs. Sharp, Jones and Company, as the owners of pottery works at Parkstone in Dorset, and retained an active interest in the business up to the time of his death, which occurred suddenly on the 22nd August, 1906.

Mr. Sharp was elected an Associate Member of The Institution on the 4th May, 1880, and was transferred to the class of Members on the 25th February, 1896.

FRANCIS WEBB WENTWORTH-SHEILDS died at Sholing, Southampton, on the 18th January, 1906, at the advanced age of 85. Born in 1820, he was the youngest son of the Rev. Wentworth Sheilds, Rector of Kilbeg and Newtown, County Meath, Ireland. His mother, a member of the Plunkett family, died during his childhood, and becoming, through his grandmother, formerly Miss Wentworth, the representative of the Irish branch of the Wentworth family, he took the surname of Wentworth by Royal license in 1877. Educated in Dublin, Mr. Wentworth-Sheilds was apprenticed in 1837 to Mr. Charles Blacker Vignoles, Past-President, under whom he gained experience of railway work. In 1843 he went out to New South Wales, where for 3 years he held the office of City Surveyor of Sydney, and subsequently became Engineer to the Sydney Railway Company, who were the first to build railways in Australia. The operations of the company being temporarily suspended in 1851, Mr. Wentworth-Sheilds resigned his office and returned to England.

In 1852 he was appointed Resident Engineer on the Crystal Palace, Sydenham, then in course of erection, and held this position until 1858. In 1857 he engaged in private practice in Westminster. He submitted designs for the construction of the Victoria Embankment, which were accepted by the Royal Commission appointed in 1861, and were subsequently carried out by the Metropolitan Board of Works on the lines of Mr. Wentworth-Sheilds' scheme. He also designed a subway under the Thames between Deptford and Millwall, which, after receiving parliamentary sanction, had to be abandoned for lack of sufficient capital.

In 1869 he was requested by the Chancellor of the Exchequer, Mr. Robert Lowe, afterwards Lord Sherbrooke, to report on the means for improved communication between England and France. In the absence of any feasible scheme for bridging the Channel, he himself designed a bridge with spans of 1,200 feet; but, after consideration of the various projects, he formed the opinion that a tunnel was preferable to any other means of communication. He was associated with the late Sir Gilbert Scott in the repair and restoration of various historic buildings, including Salisbury cathedral and the church at Stratford-on-Avon. Between 1873 and 1875 he held the office of Inspecting Engineer to the New South Wales Government.

The engineering works carried out by Mr. Wentworth-Sheilds during his long association with Westminster comprise many and diverse undertakings at home and abroad. In this country he was

responsible for sewerage works at Haileybury, Mortlake, Richmond, Barnes, and other places in the Thames valley; a large road bridge at Addison Gardens, Kensington; the renewal of the Cliff bridge at Scarborough; and, in conjunction with Professor Aitchison, the enlargement of the Rotherhithe repairing dock. Abroad, he conducted an important railway trial at Riga and designed the drainage of that city; at Oporto he designed and built the Crystal Palace exhibition building; he reported on sulphur springs in Iceland and on a Government harbour at Heligoland, and carried out various works in other countries.

In 1893 Mr. Wentworth-Sheilds left Westminster, where he was well known in parliamentary committee-rooms and at the meetings of The Institution, and passed the remaining years of his life at Sholing, near Southampton, where he had just completed sewerage works for the suburbs of Woolston and Bitterne at the time of his death. He was the Author of a well-known treatise entitled "The Strains on Structures of Ironwork," which was long a standard work of reference in that subject.

Mr. Wentworth-Sheilds was greatly respected for his generous and sympathetic character and for the high ideal of integrity and strenuousness which he held in public and private life.

He was elected an Associate of The Institution on the 1st April, 1856, and was transferred to the class of Members on the 6th December, 1859.

FREDERICK GEORGE SLESSOR, born on the 2nd October, 1831, was educated at Sherborne School and at a private school at Kibworth, and received his practical training under the late Mr. W. M. Peniston, on the Wilts, Somerset and Weymouth Railway. In 1853 he was appointed Assistant Engineer on the construction of the Somerset Central Railway, and on its completion in the following year he joined the staff of the East Indian Railway, and was engaged until 1858 in supervising heavy construction work, and on extensive surveys for a connecting line between the East Indian and Great Indian Peninsula systems. He was next employed for 3 years on the surveys for the Ceylon Railway, returning to England in 1861, when he was appointed Engineer to the Somerset Central, afterwards the Somerset and Dorset Railway. Retaining this position until November, 1874, he was responsible for the maintenance of permanent way, and for all parliamentary

and construction work in connection with the line, and in addition, he acted for some years as locomotive and carriage superintendent. In December, 1874, on the nomination of the late Sir Charles Hutton Gregory, Past-President, he received an appointment on the staff of the Cape Government Railways, acting at first as Chief Officer of Surveys and Resident Engineer, and subsequently becoming Chief Resident Engineer of the Eastern system. On the completion of 16 years' service at the Cape he retired on a pension and returned home.

In 1891, at the request of the Crown Agents for the Colonies, he went out to Johore in the Malay Peninsula, to make surveys and to report on the construction of a railway through the State. He returned in the following year, having made a complete survey through difficult jungle country and prepared a detailed report and estimates for the work. Although of reserved demeanour, a quiet humour and kindly disposition, allied with unerring judgment and fixity of purpose rendered him a good co-worker and chief, his relations with colleagues and subordinates being always just and kind. Mr. Slessor died on the 15th October, 1905, aged 74.

He was elected an Associate of The Institution on the 3rd December, 1861, and was transferred to the class of Members on the 17th January, 1865.

ALEXANDER ARTHUR DALRYMPLE SMITH died at Sunderland on the 25th January, 1906, aged 36. The son of the late Mr. Alexander Smith, shipowner, of Sunderland, he was born on the 28th March, 1869, and received his scientific training at the Durham College of Science, obtaining distinction in mathematics. He graduated in Science, with honours in engineering, in the University of Durham in 1893 and obtained a Master's degree two years later. In 1885 he was articled to Mr. H. H. Wake, of Sunderland, Engineer-in-chief to the River Wear Commissioners, into whose service Mr. Smith passed on completing his pupillage, and was engaged under him on the construction of the New South Pier. In 1897 he was transferred to the Roker Pier Works, comprising the construction of the pier and a round-head in deep water, founded on a caisson weighing 10,000 tons, and surmounted by a lighthouse. These works were carried out by Mr. Smith, under

the direction of Mr. Wake, and without the intervention of a contractor. On their completion in 1904, Mr. Smith was appointed Chief Assistant Engineer to the River Wear Commissioners, with full power and authority to act in the absence of the Chief Engineer in all matters relating to his department. The sound engineering skill and indefatigable industry which he brought to the discharge of his professional duties, not less than his sterling personal qualities, augured well for the future, and rendered his early death the greater loss.

Mr. Smith was elected an Associate Member of The Institution on the 4th December, 1894, and was transferred to the class of Members on the 29th April, 1902.

JOSIAH TIMMIS SMITH, the eldest son of Benjamin Smith, of Duckmanton Lodge, near Chesterfield, was descended from a family connected for many generations with the iron and steel trades. Born on the 19th February, 1823, Mr. Smith was educated at Mill Hill School, and then went to the Dundyvan Works to learn blast-furnace practice. Soon after attaining his majority he became a partner with his father in the Duckmanton Iron Works and later the Stanton Iron Works were built by them. About 1850 Mr. Smith spent nearly a year at the Creusôt Works, France, and subsequently spent some years with Mr. Samuel Blackwell, a well-known ironmaster of the period, before going into business on his own account in South Staffordshire. He had thus acquired wide experience in blast-furnace practice and management, and when Messrs. Schneider, Hannay and Co., the owners of rich red hæmatite mines in Furness, decided in 1858 to build furnaces at Barrow, they placed the construction of the works in Mr. Smith's hands. On their completion he undertook the management of the works. He removed to Barrow in 1860, and four years later the Barrow Hæmatite Steel Company was organized to take up the manufacture of Bessemer steel. Equipped with scientific completeness and with the most modern machinery, these works, in the course of a very few years, acquired a world-wide reputation. For more than twenty years Mr. Smith, as manager and director, was the executive head of the Barrow Works, which, under his able and progressive guidance, always retained a prominent position in the iron and steel industry.

Mr. Smith was an original member of the Iron and Steel

Institute, founded in 1869, and served on the Council of that body from the outset; he was President from 1881 to 1883. He was also an original member of the British Iron Trade Association, of which he was President from 1886 to 1888. During his long residence at Barrow he took an active part in the municipal life of the town, serving on the Town Council from 1867 to 1887, and as Mayor from 1872 to 1875. For many years he was County Magistrate for Lancashire, and later was on the Warwickshire Bench. In 1887 Mr. Smith left Barrow and went to reside at Rhine Hill, near Stratford-on-Avon. He became a Director of the Capital and Counties Bank, Chairman of the Midland Railway Company of West Australia, and of the Otis Steel Company, and was connected with other industrial companies. Although retiring to some extent from some of his engagements in later years, he continued to lead an active business life until the early part of 1905, when his health began to fail. He died at Rhine Hill, on 31st March, 1906, in his eighty-fourth year.

Mr. Smith was elected a Member of The Institution on the 3rd March, 1868.

FREDERIC JOHN RAMSBOTTOM SUTCLIFFE, born at Todmorden, Yorkshire, on the 22nd June, 1844, obtained his engineering training in the Crewe works of the London and North Western Railway, under his uncle, the late Mr. John Ramsbottom. From 1871 to 1878 Mr. Sutcliffe was Engineer to the Bowling Iron Company, and in the latter year he obtained the appointment of Chief Engineer to the Low Moor Iron Company of Bradford, retaining this position for a period of 20 years. As Chief Engineer, he was responsible for the entire management of the extensive engineering works of the company, comprising blast-furnaces, forges, mills, collieries and iron-stone mines. He resigned this position in 1898 and engaged in consulting practice at Bradford until his death, which occurred on the 11th February, 1906. Mr. Sutcliffe was a Member of the Institution of Mechanical Engineers and of the Iron and Steel Institute.

He was elected an Associate Member of The Institution on the 1st May, 1883, and was transferred to the class of Members on the 24th March, 1896.

JOHN EDWARD TANNER, C.M.G., born on the 20th January, 1834, was educated at Putney College, and obtained his practical training at the works of Messrs. Simpson and Company. Subsequently he served a pupillage to Sir Charles Hutton Gregory, Past-President, who appointed him in 1853 an assistant to the late Mr. Thomas Olinthus Donaldson, then engaged in railway construction in the South of France.

In 1855 Mr. Tanner proceeded to the Crimea, and joined the Army Works Corps before Sebastopol as an Assistant-Superintendent. Upon the termination of the war Mr. Tanner was appointed an Assistant Engineer on the Indian Guaranteed Railways in Sind and the Punjab, and arriving in India upon the eve of the outbreak of the Mutiny, he served with a body of European Volunteers until the danger was at an end. He was later appointed Engineer in charge of the Sutlej division of the Delhi Railway, including the Sutlej Bridge.

In 1871, at the request of the Colonial Office, he left India for Trinidad, to undertake the survey and construction of a railway between Port of Spain and Arima. On the completion of this work, Mr. Tanner was appointed Director of Public Works and General Superintendent of Railways in Trinidad, and in the former capacity, he initiated the general survey of the island. In 1886 he became a member of the Legislative Council, and retained his seat until he left the colony in 1893.

For his services in Trinidad he received the decoration of C.M.G. in 1894. His arduous and prolonged service in tropical climates had, however, undermined his constitution, and, owing to the failure of his eyesight and general health, he passed his closing years in comparative retirement. He died on the 6th December, 1906. Mr. Tanner was twice married: first, in 1867, to Mary, daughter of the late Mr. John Lister, J.P., of the Grange, Saleby; and secondly, to Ellen Mary, daughter of the late Mr. John K. Garrod, of The Grove, Beccles.

He was elected a Member of The Institution on the 6th May, 1862.

THOMAS JEFFERSON THOMPSON, fifth son of the late Mr. Ross Thompson, of Greenwood Park, County Down, was born on the 13th September, 1829, and received his engineering training in the works of Messrs. Kitson and Company, of Leeds, and under the

late Mr. John Goodwin, of Belfast. After serving as Assistant Engineer on the Armagh and Monaghan Railway during its construction, he went to Spain in 1858, on the staff of Mr. Charles Blacker Vignoles, Past-President, then Chief Engineer of the Bilbao and Tudela Railway, to carry out surveys for the line over the Pyrenees, on the completion of which he was appointed Engineer in charge of a division under construction. In 1862 he made a survey of the district between Durban and Pietermaritzburg, Natal, for Mr. James Abernethy, Past-President, and in the following year he was appointed Superintendent and Chief Engineer of the Bahia and São Francisco Railway in Brazil, remaining in charge until 1870, when for family reasons he was obliged to return home, but continued to act as Consulting Engineer to the company in London until 1873. In 1874 he entered the service of the Canadian Government, and took charge of surveys for the Canadian Pacific Railway through difficult country around the north of Lake Superior, afterwards acting as District Engineer on the construction of 80 miles of line eastward from Winnipeg. Between 1881 and 1885 he was engaged on the construction of the Denver and Rio Grande and other railways in America. He then returned to Ireland, where he carried out various harbour works for the Government Board of Works. Advancing in years, he was obliged practically to retire from active work in 1897. He died at Rostrevor, County Down, on the 18th March, 1907, aged 78.

Mr. Thompson was elected a Member of The Institution on the 5th February, 1867.

PERCY LEONARD ADDISON died at Park House, Bigrigg, Cumberland, on the 14th November, 1906. Born at Glasgow on the 25th October, 1855, he was the younger son of the late Mr. John Addison, at that time Resident Engineer on the Caledonian Railway. He was educated at a private school at Warwick and at Cheltenham College, and was afterwards sent to Berlin and to Cannstadt in Württemberg. Between 1871 and 1874, he obtained his practical training in the engineering departments of the Maryport and Carlisle Railway and the London and North Western Railway, and in the latter year he joined the staff of the Lancashire and Yorkshire Railway as Assistant Resident Engineer. In 1878 he obtained an appointment as Assistant Engineer on the Eastern Bengal Railway, where he had charge of a division of 60 miles, but was obliged to

relinquish the post in 1880, on account of ill-health caused by exposure during the inundations. On his return to England, he was temporarily employed in the engineer's office of the Midland Railway, and in 1883 he was appointed to superintend the mines of Messrs. D. and J. Ainsworth, of Cleator, West Cumberland, a position which he held until the summer of 1891, when his health failed him and he was obliged to relinquish the active pursuit of his profession.

From that time until his death he devoted himself to scientific studies and pursuits, especially to geology and astronomy. He was a Fellow of the Geological Society and contributed many able memoirs to various scientific journals. In 1890 he contributed a "Description of the Cleator Iron Company's Barytes and Umber Mines and Refining Mills in the Caldbeck Fells"¹ to the Proceedings of The Institution. Mr. Addison was twice married, first to Miss Grace Constance Ward, of London, in 1883, and secondly, in 1901, to Miss Mary Edene Hugginson, of Romalldkirk, who survives him.

He was elected an Associate Member of The Institution on the 7th December, 1880.

CHARLES ROBERT DUDLEY BORRETT, born on the 11th November, 1870, was the eldest son of the late Captain Thomas Borrett, R.N. He was educated at Clifton College and received his practical training in the works of Messrs. Maudslay, Sons and Field. In 1895 he entered the service of Messrs. Walter Basset and Company, and was employed on the design and erection of great wheels at Earl's Court, Blackpool, Paris and Vienna, a factory at Houdeng, Belgium, and a large ship gantry at Queen's Island, Belfast. In 1903 he went out to Bolivia to take charge of the erection of aerial ropeways at great heights in the Andes, where the climatic conditions and the heavy work entailed undermined his health. He returned home in March, 1905, and died, after a long illness, on the 25th September, 1906, in his thirty-sixth year.

Mr. Borrett was elected an Associate Member of The Institution on the 8th April, 1902.

¹ Minutes of Proceedings Inst. C.E., vol. cii, p. 283.

JONATHAN HAIGH, born at Wakefield, Yorkshire, on the 21st February, 1853, received his engineering training in the works of Messrs. Edward Green and Sons, of that city, and afterwards served a term of pupilage to the late Mr. William Crutchley, civil engineer, architect and surveyor, of Wakefield, continuing as an assistant to Mr. Crutchley until January 1875. He was subsequently employed as architectural assistant to the late Mr. William Dawes, of Manchester, and as managing assistant to Mr. Charles W. Richardson, architect and building surveyor, of Leeds and Wakefield, gaining practical experience in the design and erection of municipal and public buildings, the laying-out of building estates and the construction of new streets and drainage works.

In 1877 he became Assistant Engineer and Surveyor to the Aston Manor (Birmingham) Local Board, relinquishing that post in 1880 to take up the appointment of Engineer and Surveyor to the Abergavenny Board of Improvement Commissioners. On the Board being constituted an Urban District Council and incorporated in 1899, Mr. Haigh was appointed the first Borough and Waterworks Engineer, and retained that office until his death on the 23rd July, 1906. During this period he carried out many important improvements, comprising sewerage works, waterworks extensions and reservoirs, public abattoirs, a fire station and highway depot, recreation grounds and pleasure gardens, an isolation hospital, a new cemetery, and town hall and market improvements, beside the construction of several miles of new streets, sewers and water mains.

Many of the foregoing works were carried out by Mr. Haigh without the intervention of a contractor, and in their execution he displayed great skill and resource. One of his latest undertakings was a scheme for providing a more efficient water-supply for the borough by means of an impounding reservoir and a system of redistribution. He was a Member of the Incorporated Association of Municipal and County Engineers. Mr. Haigh was widely esteemed, alike for his professional ability and devotion to duty and for his sterling personal qualities: his death at the comparatively early age of 53 years was deeply regretted by all who knew him.

He was elected an Associate Member of The Institution on the 1st December, 1885.

WILLIAM SIMPKINS was born at Edinburgh on the 18th January, 1844. His father, Mr. William Yule Simpkins, of Inveresk, died in 1852, leaving his widow and five young children poorly provided for, and the subject of this notice, being the eldest, was in consequence obliged to go to work at a very early age to assist the family. In 1860 he was enabled to apprentice himself to Messrs. Thomas Long and Company, Engineers, of Edinburgh, with whom he remained until 1867, attending evening classes during his apprenticeship and taking advantage of every opportunity to improve his general education. In 1867 he entered the service of Messrs. James Milne and Son, Engineers, of Edinburgh, where he obtained his first experience of lighthouse work, which had great attractions for him. In 1870 he obtained a post as foreman of works under the Japanese Government, to superintend the erection of lighthouses around the Japanese coasts. He remained in Japan about 12 years, and on his return home he commenced a course of studies at the University of Edinburgh, with a view to obtain the science degree in Engineering, and although his studies were subsequently interrupted by the loss of his savings in a bank failure, his indomitable courage and perseverance enabled him to resume them in the course of a year or two, and in 1888 he graduated in Science. In the following year he entered the service of Messrs. D. and C. Stevenson, Civil Engineers, of Edinburgh, and in the course of a few years he became their chief assistant, holding that post until obliged by illness to retire from active work. As chief assistant he was engaged in the design and execution of several important harbour and lighthouse works and in the general work of the office, his ability and devotion to duty rendering him a most valuable assistant.

Of studious habits and varied interests, Mr. Simpkins was widely read and well informed in subjects of general culture. He took an active part in the proceedings of the Edinburgh Society of Civil Engineers, of which body he served the offices of treasurer and president. He died on the 30th July, 1906, aged 62 years.

Mr. Simpkins was elected an Associate Member of The Institution on the 5th May, 1891.

JULIAN STANTON WISE, born on the 19th October, 1876, was educated privately at Dover and at the Yorkshire College, Leeds, where his abilities received unique recognition in his being selected to receive the only honorary B.Sc. degree conferred on a student on the occasion of the opening of the University of Leeds. He obtained his practical training at the Thames Ironworks, Blackwall, and under Mr. A. T. Walmisley. Subsequently he was employed by the late Mr. C. E. Olander in the design of bridges and roofs for the Great Western Railway, and under Mr. F. M. Cotton, on the re-drainage of a portion of the town of Holyhead. In 1898 and the following year he carried out surveys in Russia and Asia Minor for Messrs. C. H. Walker and Company, and continuing in their service on his return to this country, he was engaged as contractor's engineer on the Birmingham, Tame and Rea district drainage and a new building slip for the Admiralty at Chatham. He also acted as their Agent in charge of the construction of the Khedivial dock at Alexandria, and the partial reconstruction of Watchet Harbour. Entering the service of the London County Council, he was employed on the construction of the Southern outfall sewer, and was engaged on similar work in West London at the time of his death, which occurred on the 17th October, 1906, in his thirtieth year.

Mr. Wise was elected an Associate Member of The Institution on the 14th January, 1902.

LIEUT.-GENERAL RAFAEL CERERO Y SAENZ, of the Spanish Royal Engineers, died at Madrid on the 29th March, 1906, aged 74. Born on the 13th November, 1831, he was educated at the School of Military Engineering, and in 1852 received his commission as lieutenant in the Royal Engineers. He served with merit and distinction at home and abroad, and saw active service as commanding officer of the Royal Engineers both in Cuba and the Philippine Islands, attaining the rank of lieutenant-general of the Spanish Army in 1889. During the course of his military career, he was employed on many special missions and on the construction of roads, buildings and military defence works in Spain and her over-sea possessions, for which various orders and distinctions were conferred upon him. He visited other countries at the request of the Spanish Government in order to investigate and report on progress in land and marine artillery, and was appointed one of the Cuban

Commissioners at the Philadelphia Exhibition of 1876. After his return from military service abroad, he was appointed a member of the Committee of Defence and President of several military commissions. In 1896 he carried out a tour of inspection of the fortified towns of the Peninsula. He was one of the plenipotentiaries appointed to conduct the peace negotiations with the United States in 1898. In 1902 he became first military aide-de-camp to the King and chief of the royal military household, and in November of the following year, having reached the limit of age, he was transferred to the reserve. Of studious habits and an accomplished linguist, General Cerero was the author of many valuable memoirs on subjects connected with both military and civil engineering.

He was elected an Associate of The Institution on the 7th February, 1865.

MAJOR-GENERAL WILLIAM HENRY EDGCOME, R.E. *retired*, who died at his residence, Coopers Hill Lodge, Englefield Green, Surrey, on the 31st August, 1906, aged 74 years, was born at Seringapatam in 1832, and, being destined for the East India Company's service, he received his training at the military college of the Company at Addiscombe. Proceeding to India, he was employed for many years on the trigonometrical survey of India and Burma. In 1859 he returned to Addiscombe as Professor of Military Drawing and Surveys, and on the closing of the College in 1861 and the transfer of the Company's forces to the Crown, the subject of this notice returned to India. For some time he was President of the Engineering College at Madras, but relinquished that position in 1871, and came to England to take up the appointment of Professor of Surveying at the Royal Indian Engineering College, Coopers Hill, a post which he held until his retirement from the service in 1885.

He was elected an Associate of The Institution on the 9th January, 1866.

JOHN THOMSON, son of the late Mr. James Thomson, was born in Glasgow on the 7th September, 1816, and was thus in his ninetieth year when he died at Tunbridge Wells on the 18th February, 1907. After being educated at the Glasgow Royal High School, he entered

the service of Mr. Thomas Kyle, a surveyor in large practice in Scotland, and amongst other works upon which he was employed were extensive surveys in connection with a scheme for supplying Glasgow with water from the Avon and the Gill, for which the late Mr. James M. Rendel, Past-President, was the Engineer. The extreme care and accuracy shown by Mr. Thomson in the preparation of the parliamentary plans, and indeed in all his work, attracted the notice of Mr. Rendel, and on the completion of the survey he offered the young surveyor a position of responsibility in his office in London. Mr. Thomson's duties were at first technical and secretarial, but he subsequently became Mr. Rendel's private secretary, and retained this position until Mr. Rendel's death in 1856, continuing to act in a similar capacity for some time afterwards under his son, Sir Alexander Rendel.

In 1859 Mr. Thomson joined Mr. A. G. Browning, another member of Mr. Rendel's staff, in business as London agents for several prominent engineering firms, an association which continued until Mr. Thomson's retirement in 1885. Since that date Mr. Thomson passed an exceptionally quiet and uneventful life at Tunbridge Wells. A man of extremely careful and frugal habits, a generous portion of the fortune which he amassed is bequeathed for charitable purposes, the Benevolent Fund of The Institution of Civil Engineers being amongst the beneficiaries.

Mr. Thomson was elected an Associate of The Institution on the 3rd May, 1859.

. The following deaths have also been made known since the 7th February, 1907 :—

Members.

ALMOTT, CHARLES SNEATH; <i>died</i> 27 February, 1907.	GORDON, GEORGE; <i>died</i> 25 February, 1907.
ATKINSON, WILLIAM; <i>died</i> 8 April, 1907.	GRIFFIN, EUGENE; <i>died</i> 10 April, 1907.
BEWICK, THOMAS BURRELL; <i>died</i> 4 February, 1907.	HAY, PETER SETON; <i>died</i> 19 March, 1907.
BLAKISTON, MATTHEW; <i>died</i> 19 April, 1907.	HODSON, GEORGE; <i>died</i> 25 April, 1907.
BRITTLE, JOHN RICHARD; <i>died</i> 25 February, 1907.	POTTER, WILLIAM FURNISS; <i>died</i> 2 MAY, 1907.
BROWN, ANDREW; <i>died</i> 6 May, 1907.	RAILTON, ALAN; <i>died</i> 5 February, 1907.
FORD, JAMES THOMAS; <i>died</i> 9 May, 1907.	REES, TOGARMAH; <i>died</i> 23 April, 1907.
	WHIPHAM, ARTHUR HENRY; <i>died</i> 11 March, 1907.

Associate Members.

COTTRELL, WILLIAM RICHARD THOMAS ; <i>died</i> February, 1907.	OHREN, MAGNUS ; <i>died</i> 21 March, 1907.
DENNIS, HENRY ; <i>died</i> 24 June, 1906.	PRINCE, HERBERT WALTER ; <i>died</i> 27 December, 1906.
JOHNSTON, CHARLES ; <i>died</i> 8 Febru- ary, 1907.	ROBINSON, JOHN NEWMAN.
MURDOCH, GEORGE BROWN ; <i>died</i> 11 May, 1907.	ROUSE, HENRY GEORGE ARCHIBALD ; <i>died</i> November, 1906.
	TOWNSHEND, BERNARD O'DRISCOLL ; <i>died</i> 24 February, 1907.

Associates.

CLUTTON, ROBERT GEORGE ; <i>died</i> 10 March, 1907.	SUGG, WILLIAM THOMAS ; <i>died</i> 28 February, 1907.
WILSON, Sir ALEXANDER, Bart. ; <i>died</i> 27 April, 1907.	

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—Sec. INST. C.E., 17 May, 1907

SECT. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS
AND PERIODICALS.*Surveys of British Africa.*

(Colonial Reports, Annual, No. 500. London, 1906.)

The First Annual report of the Colonial Survey Committee shows the work that has already been achieved in ensuring the rapid and economical prosecution of accurate surveys throughout British Africa. The Colonial Survey Committee was constituted in August, 1905, and consists of a representative of the Colonial Office, the Director-General of the Ordnance Survey, and the officer in charge of the topographical section of the General Staff, with Mr. W. C. Bottomley and Captain C. H. Ley, R.E., as Secretaries. It is an advisory committee formed at the instance of the Secretary of State for the Colonies to advise him in matters affecting the survey of British Colonies and Protectorates in Africa. The topographical section of the General Staff is issuing maps of Africa on scales of 1 to 1,000,000 and 1 to 250,000. Of the former series, 43 of 132 sheets have been published, and of the latter 185 sheets. The published sheets cover generally the Anglo-Egyptian Sudan, British East Africa, Nigeria and the Gold Coast. The survey work of the various Boundary Commissions forms the framework into which sketches made by travellers have been fitted. This material, together with certain accurate traverses and some plane-table work, has furnished the data from which the maps have been compiled. The Committee recommend the employment of natives on government surveys in tropical dependencies to as great an extent as possible to carry out operations such as are customarily performed by natives in India. The delimitation of international frontiers has been an indirect means of surveying some of the outlying portions of the tropical protectorates, and the boundaries are now, with few exceptions, well defined. In some instances curious errors have been detected in the maps, on which international agreements were based. The greater portion of the report is devoted to a detailed statement of the state of the surveys of the Anglo-Egyptian Sudan, British Central Africa, East Africa Protectorate, Gambia, Gold Coast, Northern Nigeria, Sierra Leone, South Africa, Southern Nigeria and Lagos, and Uganda. There are six index maps and reproduc-

tions of photographs of a pillar and of a trigonometrical signal on the Anglo-German boundary west of Victoria Nyanza, of a cadastral signal on the Gezireh survey, and of cutting a line through the dense tropical bush on the Gold Coast Survey.

B. H. B.

New South Wales Railway Commissioners.

(Report for the year ending 30 June, 1906.)

This report includes that on tramways, which are all worked by the Government.

RAILWAYS. ¹		1906	1905
Average mileage worked—			
Quadruple		8½	8½
Double		194	193
Single		3,178	3,079½
Sidings		457½	448

The lines taken over during the year from the Public Works Department, which constructs them, were:—

	m.	ch.
Burren Junction to Cryon, 3 July	22	70½
Casino to Grafton, 6 November	67	15½
	90	5½

The following lines were under construction at date of report:—

	m.	ch.
Manilla to Barraba	32	4
Bogan Gate to Trundle	15	77
Temora to Ariah Park	20	40
Burren Junction to Collarenebri	43	0
	111	41

	1906	1905
	£	£
Gross earnings	4,234,791	3,684,016
Working expenses	2,308,384	2,192,147
Net profits	1,926,407	1,491,869
Percentage of working expenses to earnings	54·51	59·50
Number of passenger-journeys	37,500,531 ²	35,158,150
Tonnage of goods	7,400,658	6,549,791
Tonnage of live-stock	228,834	174,424
Train-mileage	11,863,682	10,467,866
Average miles per ton of goods	65·25	

¹ The gauge of the New South Wales Government railways and tramways is 4 feet 8½ inches.

² Of these 33,347,246 belong to the suburban systems, viz., within 22 miles of Sydney and of Newcastle.

The rates per ton-mile charged for the principal classes of goods traffic are as follows, exclusive of terminal charges:—

Coal and shale	d. 0·56	Wool	d. 2·03
Firewood	0·79	Live-stock	1·75
Grain and flour	0·44	General merchandise	1·91
Hay, chaff, etc.	0·38		

The following are the receipts and expenditure per open mile in pounds, and per train-mile in pence respectively:—

	1906		1905	
	Open Mile.	Train-mile.	Open Mile.	Train-mile.
Receipts	£ 1,257·9	d. 85·67	£ 1,122·9	d. 84·46
Expenditure—				
Maintenance of way	160·3	10·92	149·7	11·26
Locomotive power	260·4	17·74	257·2	19·35
Carriage and wagon repairs	53·5	3·64	54·8	4·12
Traffic expenses	187·6	12·77	181·7	13·67
General charges, &c.	23·9	1·63	24·8	1·86
Total	685·7	46·70	668·2	50·26

Staff employed	13,478
Capital expenditure—	£
Construction	36,239,213
Rolling-stock and workshops	7,386,850
Total	43,626,063

	1906	1905
Number of engines	655	623
„ tenders	540	508
„ coaches	1,143	1,126
„ trucks	12,580	12,613

The report points out that the deficiency of 1905 of £35,079 has been turned into a surplus in 1906 of £384,980. The 1,395,796 increase in train-mileage is accounted for by the results of bringing in a uniform system of dealing with light mileage throughout the Australian States, 759,650 being due to the latter, not hitherto included. The Report refers to the approaching opening for traffic of the new Sydney central station.

TRAMWAYS.

	1906	1905
Total mileage	126·118	125·590
„ „ counted as single load.	183·012	..
Sidings, loops, etc.	29·35	..

Counted as single track, the lines in the city and suburbs of Sydney are: electric, 139·12 miles; steam, 16·48 miles; and horse, 2 B

1·23 mile. In Newcastle, steam, 19·41 miles; and in Broken Hill, steam, 6·17 miles.

	1906	1905
	£	£
Gross earnings	851,483	813,569
Working expenses	665,083	685,682
Net revenue	186,400 ¹	127,887
Electrical output in kilowatt-hours	36,137,122	33,535,887
Ditto for traction purposes only	32,315,754	30,176,807
Other purposes	3,821,368	3,359,080
Passengers carried	145,262,779	139,669,459
Cost of construction—	£	£
Track	2,032,576	2,016,520
Power-houses, rolling-stock, etc.	1,636,520	1,621,402
Per mile	29,092	28,931
Interest on capital	£5 1s. 7d.	£3 10s. 4d.
Rolling-stock—		
Vehicles of all kinds	957	948

The Commissioners imported as adjuncts to tramway service four steam motor-omnibuses, but after a trial of 4 months on one route and about 5 weeks in another, they were given up owing to unfavourable financial results and unsuitability in construction for the conditions.

C. O. B.

South Australian Railway Commissioners.

(Report for year ending 30 June, 1906.)

The report is exclusive of the Palmerston and Pine Creek line, an isolated railway in the North of Australia.

Mileage—	1906	1905
5-foot 3-inch gauge, including 11 miles } 507½		507½
26 chains double }		
3-foot 6-inch gauge	1,238	1,238

The line from Tailm bend to Pinnaroo (length not given) was in course of construction, and four lines were under survey.

	1906	1905
	£	£
Gross revenue	1,349,765	1,273,321
Working expenses	764,385	736,791
Nett revenue.	585,380	536,530

¹ The figures for 1906 include those for motor-omnibus feeders to tramways.

	1906		1905	
Number of passenger journeys . . .	10,715,343		9,866,626	
Tonnage of goods and live stock . . .	1,732,436		1,681,003	
Train-miles	3,875,167		3,773,106	
Percentage of working expenses to revenue	56.63		57.86	
	£	d.	£	d.
Earnings per open mile and train-mile .	773	83.59	730	80.99
Working expenses ditto	438	47.34	422	46.87
Average mileage per passenger	11.75		11.61	
Average mileage per ton of goods and live stock	118.38		120.04	

Detail of working expenses per open mile and per train-mile—

	1906		1905	
	£	d.	£	d.
Maintenance	117	12.60	119	13.16
Locomotive power	176	19.01	166	18.61
Carriage and wagon repair	45	4.90	41	4.52
Traffic	90	9.75	87	9.71
General	10	1.08	9	0.87
Total	438	47.34	422	46.87
	£		£	
Capital expenditure	13,610,520		13,587,406	
Nett return per cent.	4.30		3.95	
Rolling-stock—				
Locomotives	327		333	
Coaches	423		432	
Wagons	6,382		6,361	

The Report speaks of the revenue being the highest on record, attributable to the splendid season and to the satisfactory working of the agreement with New South Wales and Victoria as to adjustment of rates for competitive traffic.

C. O. B.

Victorian Railway Commissioners.

(Report for year ending 30 June, 1906.)

Mileage—	1906	1905
5-foot 3-inch gauge	3,316.37	3,312.25
Sidings	574.61	547.96
Equivalent to single track, including sidings, etc.	4,222.33	4,191.52
2-foot 6-inch gauge	81.60	81.60
Sidings	4.71	4.63
Equivalent to single track, including sidings, etc.	86.30	86.23

The increase in 5-foot 3-inch mileage is represented by the construction of the Electric Street Railway, St. Kilda to Brighton (Melbourne), opened 7th May, 1906 :—

	1906 £	1905 £
Gross revenue (exclusive of Street Railway)	3,787,619	3,582,266
Working expenses	1,999,023	1,871,138
Nett revenue	1,788,596	1,711,128
Passenger journeys (about 92 per cent. suburban)	65,088,394	59,702,050
Goods tonnage	3,376,987	3,382,788
Live-stock tonnage	299,030	245,449
Train-mileage	9,392,069	9,023,365
Revenue per open mile	£1,116	£1,059
" train-mile	96·79d.	95·28d.
Working expenses per open mile	£589	£553
" " train-mile	51·08d.	49·77d.
Percentage of working expenses to gross revenue	£52·78	£52·23

Detail of working expenses per train-mile—

	d.	d.
Maintenance	14·62	13·35
Traffic, including compensation	15·03	14·96
Locomotive running only	12·30	12·99
Rolling-stock repairs	7·84	7·31
General	1·29	1·16
Total	51·08	49·77

Capital expenditure £41,398,037 £40,635,306

Rolling stock, 5-foot 3-inch gauge—

Locomotives	504	513
Coaches	1,198	1,184
" joint stock, South Australia	18	18
Trucks	10,391	10,270
Electric cars	5	0
Motor buses	6	0

2-foot 6-inch gauge—

Locomotives	7	7
Coaches	12	12
Trucks	99	96

Electric Street Railway.

	1906 £
Revenue	1,449
Working expenses	1,141
Nett revenue	308
Percentage of working expenses to revenue	78·74
Cost of construction	£25,013
Rolling-stock	3,597
Excess of working expenses and interest over receipts	£136

Among the more usual tables there is an interesting one showing total and mileage cost, length, highest point, and ruling grade of each line.

The Report states that £719,496 of the capital is due to £406,513 for lines closed and partially dismantled, and £312,983 to cost of surveys of lines not constructed.

C. O. B.

Electrification of the Sarria-Barcelona Railway. J. PLAYÁ.

(Revista de Obras Publicas, Madrid, 1906, p. 291. 11 Figs.)

The line from Sarria to Barcelona is the first portion of a Spanish railway on which electric traction has been substituted for steam haulage. The work has been carried out under the direction of Mr. Koettlitz, the engineer to the railway company. The original gauge of the line was 5·48 feet, which is the standard for Spanish railways, but this has been reduced to 4·7 feet, which is the gauge of the existing tramway lines in the City of Barcelona. All the old rolling-stock has been taken away and electric motor-coaches with trailers have been substituted, and these are illustrated in the original. The whole of the route consists of double track and central poles with double arms, and overhead trolley-wires are used with return by the rails.

The usual train consists of one motor-coach, weighing when loaded 16 tons, and two trailers, each weighing when loaded 8 tons, making a total of 32 tons. Some of the trailers have open sides and some have closed sides.

The motor-coaches have 4-wheel Brill trucks, and each of the two axles carries a motor of 55 HP. The vehicle has two compartments for different classes of passengers and a large platform at the rear.

The Author describes the alterations which were rendered necessary in the platforms and stations, and states that the current is supplied by the Catalan Electric Company in Barcelona.

The scheduled speed of the trains is 15·5 miles per hour, as the stops are frequent on this class of suburban traffic, and the maximum grade is 1 in 40.

E. R. D.

Electrification of the West Jersey and Sea-shore Branch of the Philadelphia Railroad.

(Engineering Record, New York, 10 November, 1906, pp. 519-22.)

This is the longest main-line double-track road operated electrically in the United States, being 65 miles in length, with a 10-mile branch. It was converted in 5½ months from the date of the selection of the site of the power-house to the delivery of current to the rail. The work of reconstruction necessitated the relaying of 48·1 miles of track, the adding of 43·1 miles of new track, reconstruction of stations, &c., in addition to the electrical equipment of 150 miles of single track, with 71 miles of duplicate high-tension transmission-

line, eight sub-stations, and the construction of sixty-eight cars, all motors. Except for the branch, and some street-work where overhead equipment has been provided, 100-lb. third rails have been laid. The weight was chosen so as to be interchangeable with the track rails. The General Electric Company's design was adopted for the equipment. Alternating current at 6,600 volts is generated at the reinforced-concrete power-house of 17,069 square feet area, where it is stepped up to 33,000 volts. At this pressure it is transmitted to the sub-stations by the duplicate line, which is Y-connected with the neutral grounded, and consists of six No. 1 hard-drawn copper wires, on porcelain insulators, fixed to timber poles generally spaced 125 feet apart. At the sub-stations the current is reduced to 430 volts by step-down transformers, and then led to the rotaries and converted to direct current at 650 volts.

A unique feature of the transmission line is the method of protection from lightning, which consists of a seven-strand galvanized-steel cable $\frac{1}{8}$ inch in diameter, strung for the entire length of the line on the top of the poles 4 feet above the nearest active wire, and provided with ground connections at every fifth pole. Full descriptions of the attachments, insulation, and protection of the third rail are given, as well as the arrangements for continuity where the line crosses a drawbridge, and the details of the rail-bonding.

The main portion of the equipment of the engine-house consists of three 2,000-kilowatt, 6,600-volt, 25-cycle, three-phase Curtis turbo-generators; two 75-kilowatt, 25-cycle air-blast transformers, with three blowers each of 20,000 cubic feet capacity per minute, and a switch-board comprising three three-phase generator-panels, two exciter-panels, three blower motor-panels, one synchronizing equipment, three 33,000-volt transformer-panels, two sets of lightning-arresters and switches, six static potential-indicators, and two 33,000-volt outgoing-line panels. The boiler-house has twelve Stirling water-tube boilers arranged in pairs. Each is rated at 358 HP., and is furnished with a superheater capable of delivering steam at 175 lbs. pressure and at 125° superheat.

Each car, which is provided with a Westinghouse quick-service automatic air-brake as well as a hand-brake, is equipped with two 200 HP. electric motors, while the control system is of the Sprague automatic multiple-unit type. The controllers are so arranged that current is cut off from the motors throughout the train, and the brakes are applied automatically should the motorman release his hold of the controller-handle.

Power is provided for an express service on the main line, consisting of three cars on a headway of 15 minutes in each direction, with a maximum speed, moderated on grades and curves, of 60 miles per hour; a local two-car service at half-hour intervals for half the length and the branch; and a short suburban service at the starting-point of single cars at 10-minute intervals.

C. O. B.

Electric Lighting of Railway-Trains. R. DE VALBREUZE.

(L'Éclairage Électrique, Paris, 1906, vol. xlviii, pp. 293-301.)

Abstracts of earlier portions of the Author's description of the different systems of train-lighting by electricity have already appeared.¹ In the present article the Author describes four new systems and a recent modification of the Finney-MacElroy system, already discussed. The description of each system is accompanied by diagrams, by reference to which all the connections may be easily traced, but without which an explanation of the operation of the system is somewhat difficult. The additional systems now discussed are those of Vickers-Hall, Dowie, Bliss, and the Consolidated Railway Electric Light Company. In the original Finney-MacElroy system there were two distinct lamp-circuits, one supplied by the battery and the other by the dynamo. In the modification now described the lamps are all on one circuit, which may be supplied with current either from the battery or from the dynamo. To keep the pressure at the lamp-terminals constant two resistances are used; one of constant value in the lamp-circuit, the other in the battery-circuit being variable and regulated by an automatic apparatus.

W. C. H.

Locomotive-Parts of Cast-Steel. DU BOUSQUET.

(Revue Générale des Chemins de fer, Paris, November, 1906, pp. 287.)

In the *Revue Générale des Chemins de fer* of July, 1903, the Author described the employment of cast-steel for various moving parts of locomotives on the Northern Railway of France, and in this article he gives the results of the trials. Locomotive No. 4,708, with eight coupled wheels, was fitted in May, 1895, with the following parts of cast-steel:—piston-heads, guide-bars and their supports, and the valve-gear. After running 475,498 kilometres (294,809 miles) to May, 1906, all the parts were found to be perfectly in order, and needed no replacement.

In February, 1902, locomotive No. 4,772 was fitted with two coupling-rods of cast-steel. After running 134,224 kilometres (83,219 miles) they showed no trace of cracks.

In 1904, locomotive No. 2,245 was fitted with all the driving parts, the valve-gear and brake-gear of cast-steel. After running 99,010 kilometres (61,386 miles) to May, 1906, the various parts were found to be in good order. The one defect was in the right-hand coupling-rod, which after running 29,431 kilometres (18,247 miles) developed a slight crack, which was repaired, and after a

¹ Minutes of Proceedings Inst. C.E., vol. clxi, p. 370; vol. clxii, p. 432, and vol. clxv, p. 386.

further 69,579 kilometres (43,139 miles) was found to be in good order.

In 1903 crank-shafts of cast-steel were fitted to Nos. 324 and 2,520, and ran respectively 111,792 kilometres (69,311 miles), and 108,000 kilometres (66,960 miles). Two small cracks of no importance were the only visible defects.

These experiments prove that cast-steel parts may be safely used in many places for which forgings have always been considered necessary. H. I. J.

Tests of a Single-Phase Locomotive on the Seebach-Wittingen Railway. Dr. W. KENNMER.

(Schweizerische Bauzeitung, Zürich, vol. xlviii, p. 159. 6 Figs.)

In vol. xxxix of the *Schweizerische Bauzeitung* some account was given of experiments on the Seebach-Wittingen line in Switzerland with single-phase current at 15,000 volts for electric traction. Regular experimental running began on the 16th January, 1905, with a transformer-locomotive fed with current at 50 cycles per second. The periodicity was afterwards changed to 15 cycles per second and the locomotive altered to suit. Since the 11th November, 1905, experiments have been made with a locomotive fitted with motors receiving the single-phase current at 15,000 volts direct from the overhead wire, and the following data refer to this latter locomotive. The trials lasted 8 months in all, and took place from the 11th November, 1905, to the 2nd June, 1906, on the Seebach-Affoltern section, and from the 2nd June, 1906, to the 11th July, 1906, on the Seebach-Regensdorf section. A distance of 2,341 miles was actually travelled, or including shunting operations, etc., 3,037 miles, and 339,184 ton-miles in 1,066 journeys. The locomotive has two series-wound motors, and curves are given of the output at a constant current of 600 amperes, a constant pressure of 200 volts, a constant speed of 650 revolutions per minute, and also a curve of watt-hours per kilometer-hour.

The general results of the tests proved that a properly regulated service could be easily maintained with the use of single-phase current collected from overhead wires. E. R. D.

Testing of Coal for Locomotives. A. JACOBSEN.

(Ingeniøren, Copenhagen, 1906, pp. 269-72.)

As Assistant Engineer in the mechanical department of the Danish State Railways, the Author obtained from the Mechanical Director, Mr. Busse, the use of an old locomotive for carrying out a series of coal trials. The engine and tender were brought under a shed,

to protect them from wind and weather; the motion was removed; and the steam-pipe from the boiler was made to discharge into the bottom of the smoke-box. The chimney was prolonged upwards through the roof by a capacious funnel, in which were caught all sparks from the fuel and all dust that did not settle in the smoke-box. An ash-pan caught the ashes falling from the fire-grate. Two feed-water tanks were arranged, one on each side of the boiler, supplied with the usual water, which was fed into the boiler by two injectors; while one tank was emptying, the other was filling. The overflow from the injectors was caught. The coal was stored indoors for a fortnight beforehand, was then weighed into the tender for trial, and was weighed off the tender into the fire-box. The firing was done by the same trained fireman who had long done it during the regular running of the engine. Water and fuel consumption, fuel residues, and time, were all carefully noted. Steam-pressure was maintained at 8 to 8.3 atmospheres. In the smoke-box the vacuum was about 5.5 centimetres of water-pressure (2.17 inches), corresponding with a consumption of 3 cubic metres of water (660 gallons) per hour. The results of the trials are tabulated, and their close agreement shows the accuracy of the methods employed. On attempting to increase the rate of evaporation at the same pressure, the efficiency of the fuel was found to be diminished. The same attempt made at higher pressure likewise impaired the fuel efficiency, and increased the quantity of smoke-box dust; and, inasmuch as the percentage of ash simultaneously fell off, the value of the dust as fuel became greater. The calorimeter shows that, when free from ash, this dust can develop about 7,800 calories = 14,040 British thermal units; the quantity of dust varies largely with different kinds of coal. The chimney dust contains so much ash that its value is not great as fuel; but it is of no little use in affording an indication of the liability of the coal to give off sparks endangering adjacent property. All coal that burned on the fire-grate in the trials did so likewise in ordinary running, and conversely; whence this highly important condition is considered to be settled by the trials. In the course of eighteen months about 150 trials have been carried out, whereby the Author has been convinced of the practical trustworthiness of the plan.

A. B.

Loosening of Screw-Attachments in Permanent-Way.

L. SCHLÜSSEL.

(Le Génie Civil, Paris, vol. xlix, pp. 336-9.)

The recent experiments of Mr. Cuénot¹ have demonstrated the necessity of greater rigidity in both sleeper and rail if the present tendency to increased speed continue, but with the methods of

¹ Minutes of Proceedings Inst. C. E., 1897, v. 388.

forming the connections hitherto in general use much of the existing rigidity is lost in the joints between rail and sleeper. For these joints the screw has been used almost exclusively until now, and one of the most recent examples of this type is illustrated. In this the rail is supported at each connection on a saddle so tapered as to give the requisite inward cant, and is held down by two screws having their heads formed, on the underside, to fit the sloping lower flange of the rail. The sleeper is of channel section and a single elongated nut is used for the two screws. As regards this system it is pointed out that the bearing of the screw-head is on one side only, and that the oscillating movement caused by the varying stresses must and does tend to loosen the screws. Two methods of securing by means of clips are described, the one having been tested by the Eastern Railway Company, and the other being a modification brought forward with a view to minimise the defects found in practice to exist in the former. In the one case the sleeper takes the channel form with the flat side down, and at each connection the clips, two in number, are attached to the sides of the channel section by pins forged on them fitting into suitable holes in the sleeper. Each clip is made to embrace the lower flange of the rail, and the tightening up is effected by driving wedges between the sleeper and the underside of the rail, the clips having been placed in position previously. The wedges or keys are of considerable thickness and when made of wood were found to become permanently deformed, the elastic pressure on the rail being thus far from constant. Compressed paper was tried for the keys and was found to be successful, but its cost was so high that the system could not be made a financial success. The behaviour of the compressed paper was found so satisfactory that it has been used somewhat extensively for saddles on the wooden sleepers of the standard way. In the suggested modification the sleepers retain the channel section, but are placed with the flat side upwards. The clips, four in number for each attachment, are somewhat of the form of the "gib" in an old-fashioned engine-crosshead. Holes are punched in the sleeper for the reception of these clips, the two projections of which bear respectively on the lower flange of the rail and on the underside of the sleeper. The tightening up is effected by driving between rail and sleeper a wedge of compressed paper, the section being such that when driven from the outer side it will give the requisite inward cant to the rail. The wedges in this case are comparatively thin, and therefore less costly than those previously described.

I. C. B.

Construction of the Quebec Bridge.

(Engineering Record, New York, 15 December, 1906, pp. 689-70.)

Many of the individual members of this great 40,000-ton bridge are themselves larger than several important complete bridges, and in addition to their size, being built separately in the bridge-shops,

are seldom assembled till finally put together in the permanent structure, which operation is performed hundreds of feet above water, under exposure to possible severe storms. Hence great accuracy of workmanship is essential, and some exceptional features connected with these facts are here detailed. There are, for instance, 3,000 eye-bars weighing 7,500 tons, some of them 76 feet long with heads 36 inches wide, bored for 14-inch pins. They are made of medium open-hearth steel of an average ultimate strength of 63,000 lbs. per square inch. The manufacture of these is described, as well as the means of ensuring exact dimensions. The holes are bored $\frac{3}{4}$ inch larger than the diameter of the pins, and their size is tested by a cast-iron disk-gauge with exactly the required diameter, so that it will drop through the hole if the latter is more than $\frac{1}{100}$ inch too large. Precautions to secure perfectly matched field rivet-holes in various members are given. Some of the heaviest work in the bridge is required for the 1,350-ton vertical transverse bent over the main pier, one of the members of which weighs 112 tons. Rivets are mostly driven by movable pneumatic yoke machines, but many of them are inaccessible to these, and here pneumatic hammers are used.

C. O. B.

*Replacing Viaduct-Girders in the Reconstruction of the
Poughkeepsie Bridge.*

(Engineering Record, New York, 18 August, 1906, pp. 178-9.)

The reconstruction of the great bridge over the Poughkeepsie River, built 20 years ago, in order to carry the greater loads of modern traffic, has been already described.¹

The present article deals with the methods employed in carrying out the operations of reinforcement of the piers, reconstruction of the anchorages, construction of additional trestle-bents, construction of the new main-span centre trusses and an entirely new floor system, reinforcement of the viaduct approach-spans, and replacement of the plate-girder spans. Full particulars, in great detail, are given of these operations, which were begun in February, 1906, of the plant employed, and of the time occupied in each, one of the two lines of the bridge being set apart for the reconstruction, the other taking the traffic.

A leading article² calls attention to the importance of providing, in the construction of such large bridges as this, facilities for future strengthening, which, if originally adopted at a comparatively small expense, would greatly reduce the expenditure subsequently involved.

C. O. B.

¹ Minutes of Proceedings Inst. C.E., vol. clxiv, p. 449.

² *Engineering Record*, 18 August, 1906, p. 171.

Double-Track and Four-Track Concrete Bridges on the Philadelphia and Reading Railroad.

(Engineering Record, New York, 13 October, 1906, pp. 396-400.)

Two simple concrete semicircular-arched viaducts over Pennypack and Nashaminy Creeks are described, the former of five 60-foot spans 80 feet high and 33 feet wide, the latter of one 52-foot and five 65-foot spans, but wide enough for four tracks. These structures, which are of 1 : 3 : 6 concrete to the spring of the arch and 1 : 2 : 4 above, are not remarkable from others of the kind, but the description of the expansion-joints, which are highly effective, is worth attention. These are vertical, two over each pier, and extend from the haunches to and through the coping. These were made by first constructing the portion of the spandrel over the pier included between the sides of the pilaster, with rectangular grooves which engage with a corresponding tongue constructed on the adjacent spandrel-walls. These tongues and grooves are 6 inches deep and one-third the thickness of the wall in width. The adjacent faces of the wall are separated by two thicknesses of corrugated asbestos board, making about $\frac{1}{2}$ inch clearance. The joint in the horizontal coping-slab is not tongued and grooved, but is carried straight across the wall and filled to within 2 inches of the top with corrugated asbestos board, above which there is placed a V-shaped sheet of $\frac{1}{4}$ -inch lead with horizontal flanges gained into slots in the top of the coping at their edges. This lead plate is covered with $\frac{1}{4}$ inch of asphaltic cement sufficiently plastic to accommodate itself to the temperature movements. To ensure a sliding joint between the coping and the top of the spandrel-wall, several thicknesses of felt are used over the tongue- and groove-joint. The Pennypack bridge was built in one year by a force of seventy-five men at a cost of \$67,000 (£13,958 6s. 8d.). The Nashaminy bridge, which replaced a steel bridge, took nearly twice the time with about 100 men. The concrete in the latter amounted to 21,000 cubic yards, but the cost is not given.

C. O. B.

Three-Hinged Concrete Arch-Bridge.

(Engineering Record, New York, 22 September, 1906, p. 323.)

Without assistance from steel reinforcement, an extremely flat arch of elliptical form has been built in Brookside Park, Cleveland, Ohio. The major axis is 92 feet and the minor axis 9 feet, but there are hinges 2 feet $9\frac{3}{4}$ inches from the abutments, so that the true span and rise are respectively 86 feet $4\frac{1}{2}$ inches and 5 feet $2\frac{1}{2}$ inches, the latter being the difference of level between these hinges and the third one at the crown, where the arch is only 2 feet thick with the hinge at

the centre. The position of the hinges is such that no tension is produced. Fearing the effects of shrinkage in setting and temperature changes, in cracking the arch, the hinges were adopted. They are built up of steel plates and angles, steel shafting, and cast-iron bearing-plates, illustrations of which are given, as well as the method of fixture. When the centres were removed it was found that a deflection of $1\frac{1}{2}$ inch at the crown took place, which showed that but for the hinges a crack would have occurred. The concrete used was $1 : 2\frac{1}{2} : 5$.

C. O. B.

Erection of Arches of Reinforced Concrete. K. HJGAARD.

(Ingeniøren, Copenhagen, 1906, pp. 285-8.)

A single-line railway-bridge has recently been erected for carrying the Elgin-Belvidere railway over the Kishwaukee river, near the Belvidere terminus, Illinois, about 80 miles west of Chicago. It consists of four arches, each $87\frac{1}{2}$ feet span between centres of piers, making a total length of 350 feet. The clear opening of each span is 81 feet, the height of the piers $10\frac{1}{2}$ feet, and the intrados a circular arc of 83.36 feet radius. Each arch is constructed of a pair of ribs, 8 feet 10 inches apart, braced together by cross ribs. The width of each arched rib is 2 feet, and its depth is 2 feet 8 inches at the crown and 4 feet $2\frac{1}{2}$ inches at the haunches. Each rib is made up of sixteen trough-shaped voussoirs and a keystone. The length of each voussoir is 5 feet along the bottom or intrados. The voussoirs are all moulded of concrete in boxes made with sides adjustable for the varying depths and slopes. The concrete is strengthened by longitudinal and transverse rods of $\frac{3}{4}$ -inch round iron. For the three intermediate piers the concrete is mixed $1 : 3 : 5$, and is not reinforced; the two land-piers with the same mixture are reinforced, and supplemented by battered wing-walls. The concrete for the arches is mixed $1 : 2 : 4$. One of the land-piers, and also one of the intermediates, came upon running sand, requiring piles to be driven for the foundations; the other three are founded on gravel. Scaffolding and centering for erecting the arches were dispensed with by adopting the overhang method of erection. A light lattice girder was employed for carrying a travelling crane, which straddled clear over the full width of the arch for placing the voussoirs in position. Each voussoir was lifted by a horizontal rod passing through its centre of gravity, about which it was balanced in every position. Springing from the piers, each No. 1 voussoir bore against the abutment, and the overhang was anchored back by tie-rods to a post mounted on the top of the pier. No. 2 abutted on No. 1; and so on to No. 8. Besides being truly radial to the intrados, the faces of the joints were prevented by studs from slipping on one another. The two meeting halves of the arch were braced up a little higher than their intended ultimate

position, in order to ensure the keystone entering freely between them; as soon as it was properly in place, the turn-buckle couplings of the tie-rods were slacked, allowing the arch to settle down and take its full bearing against the abutments. A strip of sheet lead¹ inserted at the springing, between the first voussoir and the abutment, acted as a hinge during settlement; and the springing-joint was finally closed with cement. The voussoirs could be lifted with care twenty-four hours after moulding; they were mixed 1:3 with plenty of water. The ribs were erected for all four arches before being filled up with concrete; and last of all the space between them was filled up to the level of the permanent-way. The deflections of the eight ribs averaged 0·07 foot, ranging between 0·04 and 0·11 foot. The mode of erection was devised by Mr. J. B. Strauss, of Chicago; all the details were worked out by the Author, under whose direction the work was carried out, as illustrated by five photographs. The erection of the entire superstructure was completed in the course of thirty days by a staff of ordinary labourers without mishap. An average of three days sufficed for erecting the ribs for each span, and shifting the crane-girders and anchor-posts.

A. B.

Swing-Bridge over the North Sea Canal at Velsen.

(Le Génie Civil, Paris, vol. xlix, pp. 279-82.)

The swing-bridge in question carries the railway over the canal which unites Amsterdam with the North Sea. It consists of a short approach and of a swinging span with a total length of 128 metres (419·8 feet) moving about its central point and spanning two similar passages.

The girders are three in number and they are of the lattice type, the bracings generally consisting of vertical posts and with single diagonal tension members, though, in the case of the central bay, double diagonals are provided. The bridge turns about a central pivot but its weight is supported on a live roller-ring of a diameter of 10·20 metres (33·4 feet). Wedge-shaped rest-blocks are provided at the ends of each girder, and they are forced into position or withdrawn by hydraulic rams, a method which is also adopted for actuating the bolting-mechanism. The liquid required for this purpose consists of 60 per cent. glycerine and 40 per cent. water, a mixture which will remain liquid at the lowest temperatures likely to be experienced, and it is put under a pressure of 20 atmospheres by electrically-driven pumps. The accumulator within which the liquid under pressure is stored is carried on the bridge itself and

¹ This expedient had been adopted about 1827 by Trubshaw in the Grosvenor bridge over the Dee at Chester; and by Mosca in the Dora Riparia bridge near Turin. See Transactions Inst. C.E., vol. i, pp. 207 and 183.—A.B.

the usual heavy weights are dispensed with, air contained in a receiver being compressed as the liquid is pumped in and allowed to give back the energy thus stored when the resters and bolts are being moved. The turning mechanism is operated by duplicate electric motors, each acting on opposite sides of a circular rack through the intermediary of spur-gearing. The whole of the electric energy is furnished by a specially constructed station on shore.

In this station are two sets of generators, each steam-driven and of a capacity of 75 kilowatts. The pressure is 450 volts, and a regulating battery, of 252 elements and of a capacity of 270 ampere-hours, serves to equalise the load on the generators. The bridge can be opened in 90 seconds, but the usual time in practice is 2 to 3 minutes. Under normal circumstances the bridge remains open, but should the interval between any two successive trains be very short it is occasionally allowed to remain closed for this time, provided no vessel navigating the canal is kept waiting. Special arrangements facilitate the working of the bridge during the dark hours.

I. C. B.

Heavy Centre-bearing Draw-Span.

(Engineering Record, New York, 1 September, 1906, pp. 245-6.)

This is stated to be the longest and heaviest swing-span erected with centre bearing. The swing is 270 feet long over the Harlem ship-canal at Kingsbridge, New York, and carries two decks, the upper one for three lines of the rapid transit railway and the lower for two electric-car lines, two carriage-ways, and two cantilever side-walks, the whole moving structure weighing 3,000,000 lbs. All this when being moved is supported by the centre pivot, except in so far as the tipping tendency is met by eight trailer-wheels running on a 36-foot circular track.

The pivot consists of three loose disks 30 inches in diameter, supported on a cast-steel pedestal which distributes the load over a circular area of masonry 8 feet 3 inches in diameter. The upper and lower disks are of hardened steel, the former concave at the lower surface and the latter concave at the upper surface, to a radius of 12 feet 3 inches, these surfaces being polished. Between these is the third disk of phosphor-bronze with convex surfaces $\frac{1}{8}$ inch less in diameter, and with the slightly different radius of 12 feet, with oil-channels set into it. The upper disk has a small boss in the centre of the upper side to engage the pivot-cap. All three disks are held together by a 1-inch centre vertical screw, and are enclosed in a cast-steel oil-box 15 $\frac{1}{4}$ inches deep, and provided with eight vertical recesses in the inner periphery which serve as reservoirs and distribution-channels for oil to keep the disks flooded. There is a maximum pressure on the disk of 4,250 lbs. per square inch. When the bridge is closed the weight on the pivot is relieved

by means of wedges driven under the main transverse girders, the operation of which is fully described. The opening is effected easily in 4 minutes by two 60-HP. electric motors.

C. O. B.

Fall of a Reinforced-Concrete Structure in Bern.

(Schweizerische Bauzeitung, Zürich, vol. xlviii, p. 115. 12 Figs.)

The failure of a reinforced-concrete structure in Bern and the detailed report thereon contained in this article must draw attention to the necessity for more careful design. Mr. Elskes and Prof. Schüle were appointed to report on the disaster, and the article contains detailed drawings of the portions of the structure which failed. The building was new, and was specially built as a store for theatrical scenery and properties for the municipality of Bern; it was designed by Mr. von Wurstemberger, architect to the theatre company and also chief of the architectural department of the municipality. Reinforced-concrete was used for the roof and also for the floors as a precaution against fire, and tenders and detailed plans were invited from specialists. All the proposals and calculations were submitted to and approved by Mr. Bolliger, bridge engineer to the Railway Department at Bern. The designs of Mr. Lossier, of Lausanne, were approved, with Anselmier and Co., of Bern, as contractors, for the price of £812, to include the ferro-concrete only. The central third of the building had no ceiling and was open to the roof, so as to act as a store for scenery, and this is the part which collapsed. The roof was fixed and the concrete was put in position by the 29th July, 1905, and the centering was removed between 25 and 28 days later. Four bays out of five of the roof collapsed on the 23rd August. The building was a lean-to, and the total roof-span without support was 40·7 feet; each girder was straight for five-sixths of this span and was bent down for the remainder of its length to a point on the front wall at a level of 9·84 feet below the back support, and the maximum distance between the centres of the girders was 15·7 feet.

The report states that no proper inspection was made of the reinforced-concrete under construction, and that the rules drawn up in 1903 by the Swiss Society of Architects had not been followed. The concrete platform or structure of the roof between the main girders was only 3·9 inches thick, which the reporters consider much too thin for a span of 13·8 feet. The conclusion is that the structure was improperly designed and that the work had been insufficiently supervised.

E. R. D.

Remarkable Settlement of a Concrete Building in Tunis.

P. FOUNTAIN.

(Engineering Record, New York, 3 November, 1906, p. 492.)

The tilting over, owing to bad foundations, of two lofty reinforced-concrete grain-stores, one to the remarkable extent of 25° from the vertical, without distortion, and the still more remarkable restoration to verticality, are described. Counterweights in the form of sand in sacks were placed at the high side of the several floors, and in one case the ground was excavated along the foundation on the same side to allow of the soil giving way more easily in the righting movement. In the other case it was ascertained that the centre of gravity, around which as a pivot the building oscillated, was a line passing through the centre of the block, the floor of the building on one side being upheaved to the extent of 9 feet. Both blocks are now of course much below their original level. The Author concludes that although the reinforced concrete is praised for keeping the building from losing its rigidity, it would have been wiser to avoid testing this quality by building originally on piles reaching firm ground.

C. O. B.

New Hospital at Interlaken.

(Schweizerische Bauzeitung, Zürich, vol. xlviii, p. 70. 14 Figs.)

This hospital was opened in 1905, and was designed by Ernst Baumgart, of Bern. As costs are given in detail it may be useful to give them in order to afford a comparison with the costs of similar work in England, particularly with regard to the engineering work. The hospital consists of three separate blocks unconnected in any way. The main building has seventy beds, and comprises basement, ground, first and second floors, and is heated by ventilating hot-water radiators from an installation in the basement. There is also a hot-water service, electric lighting and gas service, and a system of electric clocks. The isolation block has a basement, ground and first floors, and is divided into four parts with twenty-eight beds altogether. This block is heated by a separate system of low-pressure steam-radiators. The third block contains the laundry, post-mortem room, etc. The staff consists of sixty persons in all, and the total cost of the building, including the site and the furniture, was £23,400, which is at the rate of about £240 per bed. Out of this sum the heating cost £706, the electric lighting and gas installation £414, the current and gas being both supplied from the public mains. Electric bells, clocks, laundry apparatus, etc., £468. The cost of the buildings, exclusive of the site and the furniture, but

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including all the engineering work, was £15,504, which is about £158 per bed. There are no separate sanitary towers, and the design would not satisfy modern requirements in England.

E. R. D.

Heat-Treatment of Reinforced-Concrete Columns.

H. B. MACFARLAND.

(Engineering Record, New York, 22 September, 1906, pp. 329-30.)

One of the claims of reinforced concrete to recognition is its fire-resisting qualities. This article details certain experiments made by a disinterested authority at the Chicago laboratory of the National Fireproofing Company. The object of the tests was:— (1) To determine if a reinforced-concrete column, when subject to a temperature of 1,500° to 1,600° F. for a period of 3 hours, would be impaired in strength or elasticity. (2) To determine, if possible, the effect of quenching with water a concrete column which had been highly heated. (3) To show that a reinforced-concrete column encased in a fireproof material is not impaired in strength or elasticity if subjected to a furnace-temperature of 1,600° F. for several hours. The columns, seven in number, were 10½ inches square, and in lengths of 1 foot 6 inches to 12 feet, composed of 1 : 2 : 4 concrete reinforced by a ¾-inch iron rod 2 inches from either (*sic*) corner running the entire length. All columns were tested cold for strength, and then under high temperatures. The method of application of these tests is described, and a Table gives the results.

C. O. B.

Canal of Aragon and Catalonia.

(Revista de Obras Publicas, Madrid, 1906, p. 230. 1 Map and 18 Photographs.)

The original article is accompanied by a map of the district through which the Canal of Aragon and Catalonia passes. The important siphon described in the Abstract on p. 387 was built for the supply of this canal, which is intended to irrigate an immense area in these two provinces of Spain. The official estimate of cost is £1,280,000, but as this estimate was prepared in 1864 the actual cost will probably be about one-fifth more.

The design comprises a network of canals of various sizes, of which there are to be 51·5 miles, with various sections calculated to pass 530 to 1,236 cubic feet of water per second; 57 miles to pass 530 cubic feet per second; 103 miles of branch distributing channels; and 37·2 miles of ditches.

The whole of this network will serve to irrigate 259,350 acres, and the country through which the main canals are carried is very hilly.

The photographic views show the great depth of many of the cuttings which have been necessary.

The entire work is not yet finished, but at the date of the article 21 miles had been completed from the intake to Zaiden, 12 miles to Tamarite and about 10·4 miles of the canal from Zaiden, making a total of about 43·4 miles. Much of the subsidiary work has also been finished. The total cost of the works to date has been about £720,000.

E. R. D.

Reinforced-Concrete Siphon for the Canal of Aragon and Catalonia.

(Revista de Obras Publicas, Madrid, 1906, pp. 109, 157, 217, 253, 278. 77 Figs.)

This is a long series of articles describing a very important siphon of reinforced concrete which crosses the river Sosa and the ravine of Ribabona to supply the canal of Aragon and Catalonia.¹ It consists of two pipes, laid side by side, each pipe being 12·46 feet in diameter (interior), 1,091 yards long, and designed to pass 1,235·5 cubic feet of water per second under a head of 85·3 feet.

The Hydraulic Company, of which Mr. J. E. Ribera is the head, prepared plans for the work in conjunction with Mr. A. Bonna, of Paris, and their proposals were accepted. The pipes are 6·9 inches thick, of which the inner 0·86 inch forms an armoured lining. The next layer is of sheet-iron 0·118 inch thick, which is thus protected from the action of water by the inner lining and supported by the outer thickness of 5·9 inches of concrete reinforced by rings of T-iron, which sustain the stress due to the head of water. The sheet-iron tube is constructed of separate sheets of moderate size and in lengths of 21·3 feet. It was originally intended to weld the seams by blow-pipe, and also to open out the ends of each complete tube and weld the joint in a similar way, like an Adamson seam. But this was found unsatisfactory, and, after a few tubes had been made in this way, riveting was substituted throughout, the joint between adjoining lengths being of the form . This joint was selected to allow of expansion, and was covered first with a mixture of bitumen and asphalt, and subsequently with the concrete armoured as already described.

The tubes are laid on a concrete bed, having in section the form of two semicircles butted together. The tubes are carried across the Sosa river on a special bridge, and after they had been laid they were covered with concrete so formed as to give a rounded exterior. The series of articles is illustrated by numerous photographs and plans of the work under construction.

¹ See preceding Abstract.

No work of similar importance has been carried out so rapidly in Spain. It was completed in less than 5 months at a cost of £60,000.

E. R. D.

Mechanical Haulage on the Teltow Canal. F. HOFER.

(Le Génie Civil, Paris, vol. xlix, pp. 357-62.)

Until recently all the traffic between the Elbe and the Oder had to pass through Berlin, but in 1901 the Teltow canal was commenced and it has recently been opened. This canal leaves Berlin on the north and effects a saving of 16 kilometres (9.93 miles) in the distance between the Elbe and the Oder, while at the same time enabling vessels to avoid the congested waterway which passes through Berlin. The length of the canal is 37.5 kilometres (23.25 miles), and it is divided into two ponds, the upper or eastern pond being 29.5 kilometres, or over three-quarters of the whole length. The difference in level is overcome by a single lift, but two locks side by side are used, the one forming a side pond for the other. The water available in summer is insufficient for lockage purposes, and an electrically-driven pump is provided at the locks so that the water discharged from these can again be raised to the level of the higher pond. The system of towage is mechanical throughout, and with the exception of two lengths, aggregating 4.5 kilometres (2.79 miles) where the canal traverses existing lakes of considerable width, it is effected by electric locomotives running on the canal banks. The type of locomotive in use is carried on a bogie at the fore end and on a single trailing-axle behind, the motors being on the bogie. The metre-gauge is adopted and each locomotive weighs 7.5 tons. Some interesting experiments have been made with a view to show how the tractive effort increases with the speed of towing. At a speed of 4 kilometres (2.48 miles) per hour the pull on the tow-line was 850 grammes (1.87 lb.) per ton of effective load, while when the speed was increased to 5 kilometres (3.10 miles) per hour the tractive effort was almost 60 per cent. more. The locomotives are built with all the heavy parts on the side away from the canal with the object of counteracting the overturning effort caused by the sideway pull of the tow-line. For towing through the lakes tugs are used, but although electricity, internal combustion alcohol-motors, and a similar type of engine driven by producer-gas have been tried, they have been found unable, so far, to compete with steam generated by means of liquid fuel. The tests of the engine driven by producer-gas are not, however, quite complete.

I. C. B.

Mechanical Equipment of the Teltow Canal. ERICH BLOCK.

(Elektrotechnische Zeitschrift, Berlin, 1906, 31 May and 7, 14 and 21 June, pp. 513-23, 545-52, 565-73, 586-9.)

This is an exhaustive description of the manner in which practically the whole of these canal works are operated by electricity from one central generating-station. The Teltow Canal connects the Spree with the Havel, and lies to the south of Berlin, forming a relief trade-route away from the heart of the city.

The various ways of towing barges, partly by electric motor-boats and partly by small locomotives running along the banks of the canal, the operation of the lock at Machnow (having a capacity of 3,200 tons per day in both directions), the cranes, lighting and power-supply along the route, the various bridges and the central station itself, are all fully described.

The total working costs, after allowing for amortization and interest on capital, assuming that 2 million tons of goods are to be carried annually, are estimated at 0.52 pfennig per kilometre-ton (0.102d. per ton-mile). For 3 million tons of goods this figure becomes 0.409 pfennig (0.08d.), and for 4 million tons 0.358 pfennig per kilometre-ton (0.07d. per ton-mile).

By supplying light and power at advantageous terms to consumers on either side of the canal the authorities hope, not only to increase the earning capacity of the works, but to attract new industries and factories, whilst by retaining an option on the land within 1 kilometre (0.62 mile) of the canal, unwholesome private speculation in this connection is obviated.

The article is profusely illustrated by photographs, diagrams, drawings and plans.

C. J. G.

Dredging of Ambrose Channel, New York Harbour.

(Engineering Record, New York, 29 September, 1906, p. 338.)

Dredging operations of great magnitude are in progress to obtain a minimum depth of 40 feet for a length of 7 miles through the bar. As 42,500,000 cubic yards had to be removed, and the contractors, whose rate was 9 cents ($4\frac{1}{2}$ d.) per cubic yard, failed to complete as stipulated in 1905, the United States Government took up the work with two dredges, both of which have been in operation for over a year. These, which are self-contained sea-going vessels holding the dredged material till dumped in deep water, have each a carrying capacity of 2,400 cubic yards. The dredging-pumps are of the usual centrifugal type, the pumping being done while the vessel is in motion at a speed of 1 mile to $1\frac{1}{2}$ mile per hour against, and 3 miles to 4 miles with, the current. During the 11 months ending the 31st May, 1906, 3,250,000 cubic yards were removed at an average

total cost of 5.274 cents (2.637^{d.}) per cubic yard, two-thirds of this being due to pumping, and one-seventh and one-eighth respectively to going and returning to the dump 8 miles out at sea. The material, which was sand and gravel, included much refuse from the city, and such items as paving-stones, projectiles, heavy chains, etc., necessitated thickening of metal, etc., to avoid the breakages which occurred in the early stages of operation. These results, the article states, have a significance beyond their association with harbour work, and indicate the efficient and economical use of hydraulic excavation, transport and disposition of material in the building of dams and other similar structures. It is stated that such dredging ought to be done profitably at 9 cents (4^{d.}) per cubic yard.

C. O. B.

Port of San Esteban de Pravia in Spain. P. D. TIRADO.

(Revista de Obras Publicas, Madrid, 1906, p. 42. 1 Plate.)

This article describes the present condition of the port and the improvement works now in progress. The port itself is about 2,000 yards from the bar at the mouth of the river Nalon, the largest river in the province of Oviedo in the Asturias. The town of Pravia is about 7¹/₂ miles from the sea.

The present port has only a mole about 110 yards long, and the works executed by the State comprise the mole, works for the manufacture of concrete blocks, and the removal by blasting of a rock which rose above high-water mark. There is now a depth of 10 feet at low water over that spot.

The Author gives a history of the various projects which were proposed for the improvement of the channel, and also details as to the discharge of the river. He then proceeds to describe the works in progress, which are illustrated by a double-page plate. These works comprise training-walls along both sides of the river for a considerable distance; a long wall across a bay which is to form an inner anchorage as the wall leaves approaches at each end. The training-walls are carried across existing sand-banks and shallows, which will be dredged to form a channel 260 yards wide at the mouth of the river and gradually diminishing in width to 185 yards.

The works to be completed in the year 1906 are expected to cost £336,180, and the second group, to be carried out in 1907, are estimated to cost £31,978.

E. R. D.

Comparison of Steam-Engines and Gas-Engines of High Power.

L. LETOMBE.

(L'Électricien, Paris, 1906, vol. xxxii, pp. 130-3.)

The Author, discussing the commercial efficiency of high-power reciprocating steam-engines compared with that of gas-engines for driving electric generators, points out that the efficiency of the gas-engine, unlike that of the steam-engine, does not increase in proportion to the increase of power, and that, above a certain power, the cost of gas-engines per horse-power produced is almost independent of the number of units adopted. If, therefore, a capacity of 4,500 HP. be taken as the output in the comparison of the two types, while the steam-engines may be properly made up of three units each of 1,500 HP., a better result for gas-engines may be obtained with seven units each of 750 HP. The Author gives a detailed analysis of the cost of installation, depreciation, and working expenses for each case. He shows that the gas-engine installation is the cheaper, and summarizes the results of his comparison regarding depreciation and working expenses as follows:—

	Type of Engine.	Cost per kilowatt-hour (Depreciation and Working Expenses), for a Production of 3,000 Kilowatts.
1	{ Gas-engine supplied with high-temperature furnace- gases }	0·089d.
2	Steam-engine with coal }	0·262d.
3	{ Gas-engine and producer supplied with coal at 12s. per ton }	0·203d.
4	{ Steam-engine and boiler supplied with coal at 9s. 6d. per ton }	0·371d.

W. C. H.

Noise and Smell from the Exhaust of an Oil-Engine.

G. URSIN and O. E. JØRGENSEN.

(Ingeniøren, Copenhagen, 1903, pp. 339-40.)

In August, 1906, the Authors had to report on the causes of the noise and foul smell emanating from the exhaust-pipe of a 17-HP. petroleum-engine at a chocolate factory in Copenhagen. The exhaust is discharged from the engine through a 4-inch pipe into a silencing-chamber sunk in a pit in the yard, from which another 4-inch pipe is carried up about 8 feet above the factory roof. The exhaust

takes place at irregular intervals, and is white with unconsumed vapour from the fuel, and smells offensively. The noise arises from the silencing-chamber being too small, only $3\frac{1}{4}$ times the volume of the stroke, whereas six to eight times is the general practice; for complete silence it ought to be twenty times the volume. It is therefore recommended to build a new chamber, of ten times the cylinder volume, and furnished with two baffle-plates. The top of the discharge-pipe should be enlarged to 6 inches diameter through a height of 8 or 10 feet, and should be notched down about $2\frac{1}{2}$ feet with eight V notches 1 to $1\frac{1}{4}$ inch wide, and the intervening slips bent outwards. The velocity of the blast will thereby be materially diminished before it reaches the orifice; and instead of issuing in a concentrated jet, it will be broken up by escaping through the side notches. The foul smell arises from the use of solar oil, instead of the pure petroleum for which the engine was designed. The latter, flashing at about 40° C., say 100° F., readily vaporizes in the highly-heated carburettor; but the process is far more difficult with the solar oil flashing at about 120° C., say 250° F. Some of the solar oil is destroyed in the carburettor, gradually choking it with soot, which is blown out in handfuls; some ignites only during expansion, raising the blast-pressure at discharge; and some is not burnt at all, but is blown out as a white vapour, which, besides smelling so strongly, ignites sometimes in the silencer and produces explosions. On the score of economy the Authors consider that the higher price of pure petroleum would be compensated by the saving which would be realized through its more thorough combustion.

A. B.

Burning of Cheap Fuels.

(Electrical World, New York, 1906, vol. xlviii, pp. 420-1 and 656-8.)

This article discusses the efficiency and economy obtainable in steam-power plant by the use of cheap fuels in the boiler-room, the special fuel considered being the smaller anthracites known in America as "buckwheat" coal. By a comparison of prices and of the steam-making qualities of different coals, the Author shows that the use of the smaller anthracites leads to economy in steam-production, and states that this is the fuel used in and around New York in most of the large power-stations. The second part of the article is devoted to an explanation of the practical methods of burning the coal so as to obtain from it all the heat possible. The best results are obtained with the use of a forced draught, and much depends on skill in firing and on the type of grate used. The Author gives a brief outline of the main requirements of a furnace for use with these small fuels, and then discusses and illustrates a particular type—the McClave system—as adapted to different kinds of boiler. The results are given of two tests, a

capacity test and an economy test, made with a Maxim boiler supplied with small anthracite coal, the refuse of a colliery, containing 14 per cent. of moisture and, when dry, 24 per cent. of ash and refuse.

W. C. H.

Peat Fuel in Competition with Coal. J. J. TYLVAD.

(Ingeniøren, Copenhagen, 1906, pp. 333-6.)

For domestic use peat is so cleanly, dainty, and agreeable a fuel that it is not likely to give place to coal, even though the latter is cheaper. But for industrial purposes generally, where heat is the predominant requirement, it becomes important to consider the conditions under which one or the other fuel may be preferable; and amid the large variety of applications the Author selects the firing of steam-boilers for exemplifying these conditions. Peat is commonly associated with the idea of poor furnaces or poor stoking, and coal with good furnaces or good stoking; but no such confusion can be justified, and there are many grades of merit for different combinations of fuel and circumstances. These combinations are investigated at considerable length. The first general conclusion arrived at is that the employment of a more economical furnace is attended by a greater saving of a poorer fuel: whence also the difference in loss of heat between two kinds of fuel is greatest in the least economical furnace. Similarly, making the furnace more economical by increasing its heating surface results in greater saving of heat from poorer stoking; and the difference in loss of heat between poor and good stoking is greatest in the least economical furnace. Poor fuel will accordingly entail a greater loss of heat than good fuel in the same furnace, and the difference is most prominent in a wasteful furnace. Hence the poorer fuel can be favoured at the expense of the better, by improving the furnace; and hence also peat is most advantageously employed in economical furnaces, and coal in those that are less so. On the basis of these conclusions, an estimate is attempted of the range of distance within which peat, obtained from any given source of supply, may be able to compete commercially with coal obtained from a different source.

A. B.

New Tachometer.

(Engineering News, 4 October, 1906, p. 358.)

This bi-fluid tachometer is designed to indicate speed of rotation by the centrifugal effect on a liquid contained in a rotating vessel, the difference of level being magnified by employing two liquids of widely differing densities. The heavier liquid, mercury, is contained in two small covered hemispherical cups, disposed symmetrically with

respect to the vertical axis of rotation. At the outer edge of the cover of each cup there is a small opening into two tubes inclined towards the centre and filled with lighter liquid, which is coloured to be more readily visible. These join together at the axis, and a vertical tube of much smaller cross-section is connected there. When the instrument is rotated about its vertical axis the mercury tends to assume the paraboloidal surface of a free rotating liquid, and thereby sets up a pressure at the base of the inclined tubes proportional to the speed of rotation. This pressure representing the difference in level at a free mercury-surface requires a higher column of the lighter liquid to balance it; hence the rise of the lighter liquid in the small central tube is magnified, and the speed of rotation can be read off on a scale. A closed tube surrounds the vertical tube to collect the liquid in case it overflows from the indicating tube, and to return it through openings in the inner edge of the covers of the cups.

A. W. B.

Steel-Wire Ropes. J. GOTTLOB.

(Ingeniøren, Copenhagen, 1906, pp. 289-90.)

Experiments on steel-wire ropes for hoisting and driving were published in 1902 by Professor Hrabak, late tutor in the Pribram Mining Academy. Attention is drawn by the Author to the professor's trials of the two makes known as "Albert lay" and "cross lay." The first, said to have originated in 1834 with Albert, mining superintendent at Clausthal, Harz, was a "formed" rope of three strands, each composed of four iron wires 3.5 millimetres thick (0.138 inch); both the strands and the individual wires were twisted in the same direction, giving the whole rope a tendency to untwist when hanging free with a suspended weight. In "cross lay" the twist in the rope is contrary to that in the strands. The series of trials of steel ropes of various construction had the merit of being made in deep pits, where lengths of 200 to 900 metres (650 to 2,950 feet) showed elongations of 30 to 300 millimetres (say 1 to 12 inches), which could be measured with the greatest ease. The strength of the wires tested ranged between 60 kilograms per square millimetre (38.1 tons per square inch) for iron wire and 250 kilograms (158 tons) for steel pianoforte-wire. Taking toughness also into account, wire can now be got that is completely trustworthy up to a breaking strength of 180 kilograms (114.3 tons), while that which is mostly employed both for hoisting and for driving has a strength of 120 kilograms (76.2 tons). For hoisting-ropes the coefficient of elasticity ranges between 24,000 kilograms per square millimetre (15,240 tons per square inch) for the wire itself, and 11,000 kilograms (6,985 tons) for cable laid of three ropes. For driving-ropes the coefficient ranges between 21,500 and 7,700 kilograms (13,660 and 4,890 tons). The ratios of the thickness of wire, or diameter of rope, to the diameter of sheave round which it bends are formulated. Professor

Hrabak inveighs against the practice of using strands made with a steel wire for core, wound round with six wires. Here the core being straight and the outer wires helical, their elastic elongation will be different, and the core will carry a far greater load, amounting to as much as 60 per cent. of the whole strain. He instances a suspension-bridge having a cable made of six ropes laid round a rope core, where he found the factor of safety was nearly ten times as high for the rest of the cable as for the core.

A. B.

New Conveyor for Horizontal Transport. Dr. ALFRED BRUNN.

(Annalen für Gewerbe- und Bauwesen, Berlin, 15 August, 1906, pp. 75-6.)

The apparatus of which a description and illustrations are given is intended for the rapid delivery of large masses of materials, which may be either small or large in grain, or even in the form of fine flour—as, for example, cement, lime, sand, gravel, small coke or cobbles, grains of various kinds, flour, grits and milled substances generally. The conveyance may be effected either absolutely horizontally, or with a slight rising or falling gradient, but the materials moved must be in a dry condition, or not liable to become caked together. The conveyor consists, in its essential features, of a rectangular tube or channel which is preferably made of sheet iron; the walls or sides are furnished with projecting plates or ribs, which protrude vertically from each side, and are placed slanting at an angle of about 45° with the axis. The ribs are less than half the diameter of the tube in width, so that on looking through it there is a square hollow central space not occupied by the rows of plates or bafflers. The tube is caused to rotate at any desired speed by enclosing it in a pulley, or by means of bevel-gear. It can be fed by employing a hopper, so arranged that the substance to be carried enters at any one of the corners and is directed forwards by the projecting plates. The result of the rotary movement of the conveyor is that the contents are carried forward at a very rapid rate as compared with the speed possible in an ordinary screw-conveyor, or one fitted with blades in the usual way. By reference to diagrams it is shown that the speed attained is about five times as great as in the case of a screw revolving at the same rate. It is stated that the relative weight and bulk of heavy Portland cement and light slag cement transported in a square tube 11·8 inches $\times$ 11·8 inches is about four times as great as in one 7 inches $\times$ 7 inches, the former making only 40 revolutions as compared to 50 of the other. The power required for a conveyor 246 feet long may vary between $1\frac{1}{2}$ and 3 HP., in accordance with the size.

G. R. R.

Centrifugal Pumps. R. C. WILLIAMS.

(Engineering and Mining Journal, New York, 22 September, 1903, p. 544.)

The simplicity of the centrifugal pump has in recent years attracted the attention of mining engineers, with the result that great improvements have been effected, not so much in its construction as in the adapting of it to the conditions of the mine. Experiments, carried out at considerable cost, have determined the best curve for the impeller-blade and the most efficient size of inlet and water-passages. The fact that the centrifugal pump has but one moving part, and that it will pass, not only mud and sand, but sticks and stones, recommends it for such rough work as mining and excavating generally. Recent improvements have made it suitable for any height of lift; for it will now work economically against a pressure exceeding a head of 60 feet; and by the multi-stage arrangement a lift of 1,400 feet may be dealt with. An example of such a lift may be found in California. The best efficiency is obtained with a moderately high head. Friction is reduced and impact losses are lessened by nozzle-shaped openings in the casings. The water is driven by the impeller into the small end of these nozzle-openings, its velocity being gradually reduced by the increase in the sectional area of the passage. This kind of nozzle, called the diffusion ring, enables a pump with a single impeller to deal with heads above 100 feet with marked economy. The points which determine the efficiency are, the diameter of the impeller, its width, the speed of rotation and the discharge required. Where exceptionally high heads of 1,300 to 1,500 feet have to be dealt with, it is usual to place two multi-stage pumps in series; for experience has shown that a single multi-stage turbine-pump reaches its practical limit at about 700 feet. A problem in the design which demands careful consideration is that of balancing the impellers against the thrust of the incoming water. With a single impeller and suction on one side, the thrust must be provided for by some kind of thrust-bearing. With double suction the problem solves itself. In multi-stage pumps the problem is not so simple; for if the water be led to the right-hand side of one impeller and to the left-hand side of the next, very expensive core-work in the design of the casing is necessary. But experience shows that it pays in the long run to incur this initial cost. Accuracy of construction with regard to packing-rings to prevent leakage of air into the suction end of the pump is of paramount importance; for with even a small quantity of air in the suction the pump will not work. With moderate heads, and a favourable discharge, an efficiency of 70 to 80 per cent. may be obtained from these pumps.

G. G. A.

*Electrically-driven Pumping-Plant at the Wilhelmina Pit,
Heerlen, Holland. W. PHILIPPI.*

(Elektrotechnische Zeitschrift, Berlin, 30 August, 1906, pp. 806-12.)

The shafts at this pit were sunk by the freezing system, and as water was sure to be encountered owing to local circumstances, early and adequate provision for pumping was necessary. Altogether three Sulzer multi-stage high-lift centrifugal pumps were used for each shaft, two capable of raising 1 cubic metre (35·3 cubic feet) per minute to a height of 225 metres (738 feet), and the other of 2 cubic metres (70·6 cubic feet) capacity with the same lift. These pumps are direct-coupled to completely enclosed three-phase motors of 90 and 170 HP. respectively, fixed in the framing above the pumps. In order to be able to use the pump power-plant for general purposes after completion of the shaft-sinking operations, a supply-voltage of 2,000 volts was chosen, this having to be stepped down to 500 volts for the pump-motors owing to risk of leakage in a wet shaft. The motors are water-cooled from the first stage of the pump and are provided with an internal fan to ensure efficient cooling of the rotating parts. The overall efficiencies of the pumps at full load are 59 and 64 per cent. respectively, and they are started through auto-transformers at successive pressures of 250, 375 and 500 volts, the first voltage being so chosen that it suffices for starting under load.

The pumps can be lowered into the shaft at a speed of 0·13 metre (0·43 foot) per second by means of an electrically-driven double-drum hoist. An 80-HP. three-phase motor drives either barrel through a clutch, and the hoist is so arranged that on completion of the shafts an increased hoisting-speed of 2 metres (6·56 feet) per second, for passenger and goods purposes, may be obtained, by using twin instead of triple reduction-gearing. An auxiliary 50-HP. hoist for a useful load of about 1 ton is provided to bring up material during the shaft-sinking operations at a maximum speed of 1·8 metre (5·9 feet) per second. The pump delivery-pipes are carried up between the winding-ropes and are steadied by them, the sections being screwed together as the pumps descend. The electric-supply cables are paid out on to one winding-rope from a drum at the side of the shaft. A lead-covered cable being unable to sustain the repeated flexure due to winding on and unwinding from a drum, a special rubber-covered cable was adopted.

The advantages as regards safety, reliability and economy of electrical working, as against steam working, are fully dealt with, and the article is accompanied by a number of photographs and diagrams.

C. J. G.

Storage of Coal under Water.

(Engineering and Mining Journal, New York, 15 September, 1906, p. 499.)

The system of coal-storage by submergence, which has been the subject of much discussion recently, has been adopted on a large scale by the Western Electric Company for its new plant, west of Chicago. Twelve pits have been constructed, each about 80 feet long by 25 feet wide and 16 feet deep, the walls of which are formed of cement. They lie in a solid block of three rows of four in a row, the rectangular space thus occupied being about 320 feet long by 75 feet wide. Longitudinally the division-walls are wide enough for a railway track. Two of these lines run through from the storage-yard, so that the coal can be shot from the trucks into the pits beneath on each side. Under the railway lines there are arches in the separating walls, eight for each pit, forming a connection between the pits. The end concrete walls are 18 inches thick. Water is led to the pits by a 12-inch pipe, which delivers it near the top, so that the coal can be readily flooded when required. The storage capacity of these pits is estimated at 14,000 tons. A steam-shovel is to be used for reloading the coal.

G. G. A.

Determining the Calorific Value of Coal from an Approximate Analysis. GOUTAL.

(Stahl und Eisen, Düsseldorf, 1907, p. 272.)

The following formula is intended for use in approximately determining the calorific value of a fuel when only the fixed carbon, volatile matter, water and ash have been determined:—

$$82 C + a V = \text{calorific power.}$$

Where C = the coke carbon, so-called fixed carbon, V = the volatile matter other than water, and *a* a variable coefficient depending on the proportion of volatile matter in the pure fuel, i.e., calculated free from water and ash. The values of *a* are as follows, for fuel with less than 40 per cent. of volatile matter.

V	a	V	a	V	a	V	a
Per Cent.	Calories.	Per Cent.	Calories.	Per Cent.	Calories.	Per Cent.	Calories.
5	145	14	120	23	105	32	97
6	142	15	117	24	104	33	96
7	139	16	115	25	103	34	95
8	136	17	113	26	102	35	94
9	133	18	112	27	101	36	91
10	130	19	110	28	100	37	88
11	127	20	109	29	99	38	85
12	124	21	108	30	98	39	82
13	122	22	107	31	97	40	80

Water is first determined by drying at 115° C. 2 grammes of fixed carbon by a coking test of 5 grammes, the crucible being kept heated for about 3 minutes after the disappearance of flame and ash on 2 grammes of the coal. Thus, in a coal giving 86.7 per cent. fixed carbon, 10.05 per cent. volatile matter, ash 1.45 per cent., and water 1.80 per cent., the corrected value for the volatile matter is

$$V^1 = \frac{V}{C + V} = \frac{10.05 \times 100}{86.70 + 10.05} = 10.4,$$

the corresponding value of a in the above Table = 129, giving as the total heating power

$$82 \cdot 86.7 + 129 \cdot 10.05 = 8,406 \text{ calories.}$$

The value found by direct experiment in a calorimeter was 8,404. The formula is correct to within about 1 per cent., and the error exceeds 2 per cent. only with anthracites or lignites.

H. B.

New Method of Discharging Mine-Trucks. ERSKINE RAMSAY.

(Engineering and Mining Journal, New York, 20 October, 1906, p. 734.)

A novel method of discharging mine-trucks was put in operation some 5 years ago at the Smythe Slope Red Ore Mine of the Tennessee Railroad Company by the Author, who now gives the results of experience, and describes the system in some detail, with the aid of drawings and photographic illustrations. The distinguishing feature of this system is the overturning of the trucks, either singly or in a train of several trucks, to discharge their contents. The loaded trucks are run into a cylindrical structure, 6 feet 3 inches in diameter, called the dumping-cylinder, in which they are held in position by special devices for retaining the wheels in place. Thus automatically fixed, the cylinder is made to revolve by means of a wire rope driven by a small steam-engine designed for that purpose. The dumping-cylinder, which is open in its upper portion, is set over a series of bins for the reception of the ore or the coal. As it revolves, the trucks are inverted, and their contents are shot out simultaneously into the bins or railway-trucks beneath. When the cylinder comes to rest again in its original position, the train of empty trucks is run out by gravity. Actual observation shows that the whole operation of running a loaded train of five 2-ton trucks into the cylinder, discharging the load, and running the empty train out, may be performed in a few seconds.

The Author describes the construction of the dumping-cylinder, and points out numerous advantages, apart from the saving of time, afforded by this system. These advantages are mainly in the simpler, stronger and cheaper construction of the trucks and their increased durability due to less wear and tear.

G. G. A.

New Electric Tipping-Truck.

(Engineering and Mining Journal, New York, 25 August, 1906, p. 353.)

A new form of electric tipping- or dumping-truck for railway and mining work, promising to cover a wide field of usefulness, has been designed and built by the Jeffrey Manufacturing Company of Columbus, Ohio. The truck consists of a structural steel frame on which is mounted a body or hopper of heavy sheet-steel suitably braced and reinforced, and so supported on the frame that its weight when loaded is uniformly distributed. The capacity is about 12 tons of run-of-mine coal. Two motors, each of 250 volts, are geared through a single reduction, one to each axle, the gear being enclosed in dust-proof cases and running in oil. The most novel feature in this design is the arrangement for easily and rapidly discharging the load. To facilitate this, the bottom of the truck is made to slope from a "hip" or ridge in the centre down to the edge of each side, and at the front end there is a triangular face or slope to the bottom edge of the front door. The angle of slope is adjustable to the nature of the materials to be dealt with. The doors are hinged to the body of the hopper, and are so hung that they open slightly by their own weight when the holding chains, of which there are three to each door, are loosened. The two side doors are usually operated simultaneously, the front door being worked independently. But the method of operating these doors may be arranged to suit the purpose for which the truck is being used. Thus each door may be worked separately, any two together, or all three simultaneously. The mechanism for operating the doors, which is self-locking in any position, is easily and quickly manipulated by two vertical windlass-shafts and hand-wheels on the platform at the back end of the truck in which the man-in-charge sits. A third vertical shaft and hand-wheel works the brake. Tipping the material from the front and the two sides will gradually form a fill or an embankment on which extensions to the track may be laid. Two illustrations of this form of truck are given.

G. G. A.

Mining and Ballast-Truck: Wheels.

(Engineering and Mining Journal, New York, 18 August, 1906, p. 303.)

The wheels of mine- and ballast-trucks used in all kinds of excavating work are subjected to very rough usage as a consequence of badly-laid rails and neglect of lubrication. They have to be designed, therefore, to meet these conditions. The Aldrich Mining Company in Alabama have adopted a new design which is said to have proved very satisfactory in practice. This wheel is a solid casting, and, except the oil-plugs, has no parts which can be detached or loosened. The main purposes in this design are to secure the

greatest strength for a given weight of material, uniform wear of parts, and ease and certainty of lubrication. A strength greater than that of wheels with spokes is obtained by bracing the sides of the rim with plates. To retain the advantage of spoked wheels for spragging, a wedge-shaped lug is provided on which a hook is made to catch to hold the wheel. The nave presents an integral bearing-surface, bisected by a vertical longitudinal plane through the centre of the tread of the wheel. The pressure per square inch is therefore the same at all parts of the bearing-surface; and the wheel moves in true alignment with the direction of the motion of the truck until it is completely worn out. The most noticeable feature is the method of lubrication. The wheel is cast with webs enclosing a large oil-chamber, which, extending from hub to rim, has sufficient capacity to contain a supply for several months. The feeding from this large quantity of lubricant takes place through an entirely open and unobstructed longitudinal slot in the nave leading directly from the reservoir to the axle, and so proportioned as to catch a suitable amount of the film of oil on the sides of the reservoir as the wheel revolves, and feed it to the centre of the bearing-surface. The construction of this wheel is shown in a side-elevation and a cross-section.

G. G. A.

Electric v. Air Rock-Drills.

(Engineering and Mining Journal, New York, 23 September, 1906, p. 549.)

In this article the Author sums up the results of a discussion on the relative economy of electric and air rock-drills. It will surprise many engineers to learn how wasteful of power the air-drill is. Mr. C. E. Hutton read a Paper on this subject at a recent meeting of the South African Association of Engineers, in which he showed that a $3\frac{1}{4}$ -inch drill required when running an expenditure of no less than 28 I.H.P.; and his conclusions were confirmed by Mr. K. Schweder, whose tests showed that the actual energy imparted to the rock by a $3\frac{1}{4}$ -inch drill is only 1.7 HP. With 28 HP. at the compressor the efficiency at the drill-bit is about 6 per cent.; and this computed back to the potential energy of the coal is only about 0.6 per cent. Mr. C. A. Chase, the General Superintendent of the Liberty Gold Mining Company at Telluride, Colorado, reports a comparative test made with a $3\frac{1}{4}$ -inch air-drill and a Temple electric drill of corresponding dimensions. With the air-drills, the motor input at the compressor, i.e., the actual energy delivered, was 50 HP. for two drills, or 25 HP. per drill. With the electric drills, which accomplished slightly more work than the air-drills, the consumption of power was only 5 HP. per drill, a figure which agrees closely with the experience of Mr. Barnes in the Yak tunnel at Leadville. Such results as these afford a reasonable hope that the electric drill will soon find

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general application and be a means of realizing the great economy which has long been expected of it. G. G. A.

Electric Air-Drill. F. RICHARDS.

(Engineering and Mining Journal, New York, 13 October, 1906, p. 699.)

In a recent discussion on the relative merits of air and electric rock-drills, the Temple so-called electric drill came into greatest prominence as giving the best all-round results. The expenditure of power with this drill is only one-fifth of that required for an air-drill, and it possesses certain other advantages over the latter. In the Temple drill, electricity is the motive power; but the power is applied to the piston through the medium of compressed-air. The drill proper consists of a cylinder sliding in a shell with a feed-screw, the shell being mounted on a tripod bar or column in the usual way. The piston and the turning mechanism are similar to those in the ordinary air-drills; but there are no air-valves. The cylinder is connected at each end by means of a $1\frac{1}{2}$ -inch rubber hose, 12 feet long, with a double cylinder air-compressing pump worked by an electric motor. The pump with its motor is mounted on a little truck. The motor is geared to a shaft carrying two cranks—set 180° apart—which operate alternately the two single-acting trunk-pistons of two vertical air-compressing cylinders. Through the connecting flexible hose there are thus two distinct bodies of air which play backwards and forwards without in any way communicating with each other. By the alternating pulsations of these two bodies of air, the piston is driven up and down in the cylinder. The normal pressure of these bodies of air is about 30 lbs.; but the pressure is alternately much greater and much less than this for each rotation of the crank-shaft and each corresponding stroke of the drill. At ordinary speed the drill makes about 400 strokes a minute.

This is a simplification of the usual air-operating arrangements. All the parts of the drill which usually give trouble and cost so much for repairs and renewals are eliminated; and the compressors, which in this case may be called pulsators, have no valves and no water-jackets. There is no heating up in working, as the heating and cooling effects of compression and re-expansion neutralize each other. A noteworthy feature of this drill is the heavy blow it strikes. Of course, no vibration can be transmitted back to the motor. Another advantage it possesses, of considerable practical importance, is its tendency to release itself when the bit sticks in the bore-hole. With ordinary drills much time is often lost in this way. When the bit sticks the motor and compressor continue to run, and some rapid jerks in both directions usually liberate the drill in a few seconds. One of these drills is now being used in the Yak tunnel at Leadville, over 4 miles from the powerhouse. G. G. A.

Electric Plant at the Eustis Mine, Quebec. CLAUDE T. RICE.

(Engineering and Mining Journal, New York, 10 November, 1906, p. 887.)

At the Eustis Copper Mine, in the province of Quebec, an electric power-plant possessing some novelty has recently been installed. The plant, which is driven by water-power, is 2 miles from the mine, and the current is transmitted along three bare copper wires. The principal new feature consists of two alternators, mounted on the same shaft and run in parallel. The water from the dam is carried by a flume to three pairs of 18-inch special horizontal turbines mounted on one long shaft, on each end of which is rigidly coupled a rotary-field alternator, one of 150-kilowatt, and the other of 200-kilowatt capacity. These alternators generate a three-phase, 25-cycle, 2,200-volt current. The shaft makes 500 revolutions per minute, and valves are arranged to run one, two or three pairs of turbines according to the power required. In this way a great saving of water is effected. The fields of both alternators are excited by a 13-kilowatt generator driven by a belt from a pulley on the turbine-shaft. Both fields are in parallel. There is a reserve exciter, run by a separate water-wheel, to be used in case of a breakdown of the other. An automatic regulator, inserted in the fields of the alternators, keeps the current properly distributed between the two, and thus the primary voltage is kept constant.

When only one alternator is generating a current and it is desired to use both, the field of this alternator is thrown into circuit, and when the voltage is equal to that generated by the other machine the alternator-circuit is connected to the generator in step. This design removes the difficulty attendant on running alternators in parallel; for there is no trouble in getting the two in step. The only difficulty is in connecting the two alternators in phase. This was accomplished in the following manner:—One alternator was coupled to the turbine-shaft. Then the other was lined up with the shaft and the couplings of each were brought so near together that they almost touched. The second alternator was run as a synchronous motor, and when synchronism was established, the faces of the couplings, which had been previously blackened by camphor-smoke, were scratched with an awl drawn rapidly across the two coupling-surfaces. Holes were then bored and the alternator was rigidly fastened to the turbine-shaft. The alternators were then always in phase. The plant gives a total efficiency, including the transmission circuit, of 75 to 50 per cent. according to the load. The electric efficiency of the alternator is 90 to 93 per cent.; while that of the water-wheel varies between 80 and 60 per cent. according to the load.

G. G. A.

Electric Driving of Winding-Engines. R. DE VALBREUZE.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 90 and 130.)

The Author continues his discussion¹ of the most recent practice in the application of electric driving to the winding-engines of mines, and in this article gives details of the construction and capacity of the machines installed at the Lens mines, the mines of the Compagnie des Mines de Béthune, and the Karwin mines. In all three cases three-phase currents are used, and in this description special attention is given to the various safety-devices employed.

W. C. H.

Electricity in the Rolling-Mill.

(Engineering and Mining Journal, New York, 27 October, 1906, p. 770.)

One direction in which electricity has made notable progress is in its application to rolling-mills. Blooming-mills require the prime mover to be self-starting and reversing, and all types must have enormous overload-capacity. The conditions seem to be most completely met—far beyond anything achieved by the older methods of engine-drive—by electric motors receiving current from generators connected directly to gas-engines. Compound-wound motors are well adapted to the widely varying load, and the need for a roughly uniform speed between the momentary overload. The system is now in use in many parts of the United States, three-high rolling-mills being driven with entire satisfaction. For the Youngstown, Ohio, plant of the Carnegie Steel Company a single motor has been installed complete with yoke-shaft, pedestals and armature for raising and lowering the tables of a blooming-mill. This motor is of 180 HP. and 230 volts, and makes 88 revolutions per minute. The gear-reduction for the machine will be about 6.5 to 1, based on a speed of 100 revolutions of the motor-shaft. The motor will be required for continuous running for 24 hours without rising in temperature in any part more than 45° C. above the surrounding atmosphere and without sparking at the brushes. The machine is to be used to raise and lower both front and rear tables of a three-high blooming-mill table, and to make fifteen operations (seven and a half complete cycles) per minute. No binding-wires will be used on the body of the armature. The system of developing a high torque at starting has done much to encourage the application of electricity to milling operations.

G. G. A.

¹ See Minutes of Proceedings Inst. C.E., vol. clxvi, p. 438.

Use of Grout in Sinking Shafts through Water-bearing Strata.

H. SCHMERBER.

(Le Génie Civil, Paris, vol. xlix, pp. 263-78.)

The earlier attempts at consolidating water-bearing strata, by the injection of Portland-cement grout, were all conducted with the object of making tight the leaky tubbing of existing pit-shafts, but the process, when carried out with care, was found capable of giving such satisfactory results that in 1904 the Bethune Mining Company decided to sink a new shaft through very bad ground by this means. In order to do so a series of vertical boreholes were put down round the site of the new shaft, and grout was forced in from time to time as each hole was carried down. The process was quite successful in consolidating the material through which the shaft was eventually sunk, and it has since been repeated with equally satisfactory results at the "King George" pit in Saxony. In both these cases it was found that the quantity of cement for each injection varied through wide limits according to the inclination of the water-bearing bands, and that when these approached the vertical not only was the quantity of cement required excessive but the success of the operation was by no means so pronounced. When the strata are thus steeply inclined greater efficiency has been obtained by sinking the shaft by short lengths and injecting each new length in advance by means of radial boreholes driven from the last completed length of shaft. In all cases the greatest care is necessary to prevent the fine mud from the boring mixing with the grout, and if similar material is thought to exist among the permeable strata a plentiful supply of fresh water should be forced down the injecting-pipe before the grout is admitted. As compared with the freezing process it is claimed that the injection of grout is much cheaper; and, further, that the result of a breakdown in the plant is trivial, whereas if with the freezing process any considerable stoppage takes place the results may be very serious.

I. C. B.

Shaft Loading-Places in the Pribram Mines. H. STEFAN.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, Vienna, 1907, p. 65.)

The ores produced in the Pribram mines in 1905 amounted to about 45,500 tons derived from 233,000 tons of material broken in the workings; about 70 per cent. of this quantity came from depths greater than 700 metres, and more than half of it from between 900 and 1,100 metres, which was raised through the seven winding-shafts, of which the particulars are given in the following Table:—

Names.	Surface-Height above Sea.	Depth.	Section.	Deepest Level.	
	Feet.	Feet.	Metres.	Number.	Feet.
Anna	1,739	3,554	2 : $\begin{cases} 6 \\ 5 \end{cases}$	31	3,430
Prokop	1,819	3,394	2 : 6	30	3,345
Adalbert	1,750	3,666	2 : 6	32	3,606
Franz Josef	1,726	3,640	2 : $\begin{cases} 6 \\ 5 \end{cases}$	32	3,583
Maria	1,784	3,695	2 : 6	32	3,640
Rudolf	1,788	1,676	2·5 : 6	19	1,649
Stefan	1,886	1,561	2 : 6	17	1,476

The shafts are rectangular in section, 2 metres in breadth throughout, but varied in length from 6 metres at the surface to 5 metres in the lower parts of the deeper ones. The cages have two decks, but only the lower one is used in winding minerals, from 1 to 1·3 ton forming the load for the iron tub of 26 cubic feet capacity. The average speed in the shaft is 5 to 6 metres, rising to a maximum of 12 metres per second. On account of the great depth of the mines, particular care is exercised in the classifying of the material, to avoid as much as possible sending waste material to the surface. For this purpose the ground at the junction of the levels with the shafts, the latter being in all cases vertical, is cut back from the shaft parallel to its long side into a chamber about 20 feet by 30 feet and 35 feet deep, to the filling-place in the shaft below. The portion below the level is lined with masonry and is divided by cross walls into four bins or pockets, each of about 600 cubic feet capacity with discharging-hoppers at the bottom, and flat-arched roofs with a charging-hole in the centre. A flat floor in armoured concrete or covered with iron plates is laid above the roof of the bins on which the trams from the workings are discharged, and the material is picked over and classified into smalls, stamp-stuff, lumps of clean ore, etc., each class being placed in a different clearing, while the waste rock is sent back for stope-filling. When a quantity of 80 or 100 loads has accumulated the winding begins, that being about sufficient to keep the engine going through the entire length of an eight-hour shift.

Winding goes on continuously throughout the 24 hours, the changes to different levels, which take fifteen minutes to half-an-hour for adjusting the length of the rope, being done as much as possible only at the shift-changes. By this arrangement the mine tubs are kept entirely apart from those used in the shaft, and the service can be kept going independently of the fluctuations in the underground haulage. The return wagons are mostly sent back with waste filled from the spoil-heaps at the surface, to be used in filling old workings or disused levels, which affords a useful counterbalance to the ascending loads.

H. B.

Pure Alloys of Tungsten and Manganese, and the Preparation of Tungsten. G. ARRIVAUT.

(Comptes Rendus de l'Académie des Sciences, Paris, 1906, vol. cxliii, pp. 594-6.)

Alloys of tungsten and manganese may be prepared by acting on a mixture of the oxides of these metals with powdered aluminium, but the separation of the alloys from the scoria is difficult unless the operation be carried out on a large scale. The Author has, however, succeeded in getting good results with relatively small quantities of re-agents by adding tungsten anhydride and manganese dioxide in suitable proportions to the lower oxides. The heat of the re-action is thus increased by the excess of oxygen present. Pure alloys of 12 to 60 per cent. of tungsten have been thus prepared. These alloys appear not to contain the metals in the combined state, as when treated with hydrochloric acid they give a residue of pure tungsten, thus providing a new method of obtaining the metal which is much easier than the alumino-thermic process.

W. C. H.

Pohl-Croasdale Volatilizing Plant.

(Engineering and Mining Journal, New York, 3 November, 1906, p. 819.)

The Pohl-Croasdale process of volatilizing metals has been undergoing experiments for several years past. That the results have been satisfactory is shown by the fact that the Rigby Mining and Smelting Company at Mayer, Arizona, have put into commission a new plant of 125-ton capacity to work the process for the first time on a commercial scale. Briefly the process is as follows:—Ore is crushed to 20-inch mesh by the usual methods of dry-crushing; salt is mixed with the crushed ore, and the mixture is exposed to a chloridizing roast in an oxidizing atmosphere at 1,000° C. The metals, gold, silver, copper and lead, which are volatilized, are cooled by contact with sheet-metal flues, precipitated as fine dust, and further treated to recover the valuable products sought.

The plant is arranged on the unit basis, each unit being independent of the other. It consists of a furnace, a set of collecting-chambers and cooling-flues, a blower with connecting pipes, a condensing-chamber and a bag-house. The furnaces are without stacks, and all draught is provided in the vacuum created by the blowers. The gases are drawn into the condensing-chambers and bag-house, while the flue-dust, or precipitate, is taken to the filter-house and treated in leaching-tanks for the separation of its several constituents. The power-equipment consists of three steam-engines and the usual ore-crushing and grinding machinery, belted rolls and screens and dryers.

G. G. A.

Sulphur in Iron-Castings. R. MEEKS.

(Engineering and Mining Journal, New York, 18 August, 1906, p. 297.)

In an article entitled "Notes on Car-Wheels," the Author points out the danger, in the case of castings on which human life depends, of the iron absorbing sulphur from the foundry-facing, the coal in which often contains a high percentage of sulphur. It is generally believed that a car- or mine-truck wheel is made of iron of very pure quality relatively to its sulphur-percentage. To test the question of absorption from the foundry-facing, six truck-wheels, weighing 600 lbs. each, were cast, and samples of the iron were taken from the wheels at two points, the hub and the plate on the face side of the wheel, the part which gets the "strongest" facing. Test-bars were cast at the same time in independent moulds from which no sulphur could be absorbed. The results of these tests showed a mean of 0.196 per cent. of sulphur in the test-bars, 0.215 per cent. in the hubs, and 0.244 per cent. in the plates. All the sulphur content above 0.196 per cent. must have been absorbed. The portion of the wheel least likely to absorb sulphur would be the nave, because it contains a large volume of metal and also because it comes into contact with a dry sand core. The high percentage in the plate is remarkable, and points to the need of care in purchasing and using facing. In taking the iron samples for analysis the outer skin was rejected, and the borings were made to penetrate $\frac{1}{2}$ inch into the metal.

G. G. A.

Hardening- and Tempering-Oven with Electrically-heated Melting-Bath. L. M. COHN.

(Elektrotechnische Zeitschrift, Berlin, 2 August, 1906, pp. 721-5.)

The oven consists of a cast-iron casing lined with firebrick, within which is placed a crucible separated from the firebrick by a layer of asbestos. Alternating current (to minimise electrolytic action) is passed between two plates of soft iron, acting as electrodes in the crucible, which contains a suitable fusible salt, the composition of which depends on the temperature required. For temperatures over 1,000° C. (1,832° F.) pure barium chloride (melting-point about 950° C. (1,742° F.)), and for lower temperatures a mixture of two parts of barium chloride to one part of potassium chloride melting at about 670° C. (1,238° F.), is used. The salts in question being practically non-conductors when cold, but good conductors when molten, an auxiliary carbon electrode is required to start the fusion and form a strip of molten salt between the two iron electrodes, whereupon the rest of the salt in the crucible gradually melts.

The temperature of the oven being dependent on the current

passing through the molten salts, an oil-insulated auto-transformer giving a number of different voltages is employed in connection with an auxiliary resistance, or, in cases where direct current only is available, a rotary converter may be installed. The temperature of the oven can be most accurately recorded by means of a pyrometer and a d'Arsonval galvanometer suitably calibrated, and, with the exception of a layer 10 millimetres ($\frac{3}{8}$ inch) thick at the top, is found to be practically uniform throughout the molten mass and absolutely uniform in any given horizontal section. Between temperatures of 880° C. and 1,300° C. (1,616° F. and 2,372° F.) the power required to work the oven varies between 5·4 and 12·25 kilowatts, while about half an hour suffices for starting.

The advantages claimed are:—uniform heat of bath and therefore of the steel to be hardened, accurate measurement and adjustment of temperature, increased speed in heating and manipulation, absence of failures, unaltered percentage of carbon in the steel and economy and cleanliness in working.

C. J. G.

Oil-Shales of the Lothians. H. M. CADELL, J. S. GRANT WILSON,
W. CALDWELL and D. R. STEWART.

(Memoirs of the Geological Survey, Glasgow, 1906.)

This monograph on the Scottish oil-shale industry covers 194 pages, with 3 plates and 64 illustrations in the text, and is divided into three parts, dealing respectively with the geology of the oil-shale fields, with the methods of working the oil-shales, and with the chemistry of the oil-shales and the processes and products of manufacture. The first published description of the oil-shales was a note contributed by Mr. Cadell to the British Association in 1885.¹ More detailed papers were contributed by him to the Iron and Steel Institute in 1888² and to the Institution of Mining Engineers in 1901.³ In the course of the recent revision of the carboniferous areas of the Lothians by the Geological Survey Mr. Grant Wilson obtained much further information from the various mine managers. In the search for oil-shale heavy expenditure has often been needlessly incurred through insufficient boring. For percussive boring the prices ruling in the shale district are 4s. 6d. to 5s. 6d. per fathom for the first five fathoms, 9s. per fathom for the second five fathoms, and so on, increasing by 4s. 6d. per fathom on the completion of every five fathoms. The cost of rotary boring is about the same. Access to the seam is usually obtained by an inclined shaft driven in the middle seam, the other seams being entered by level cross-cuts

¹ Report of the British Association, 1885, p. 1037.

² Journal of the Iron and Steel Institute, 1888, No. II, p. 150.

³ Transactions Inst. Mining Engineers, vol. xxii, p. 314.

driven from one to another. The oil-shale is generally worked the pillar and stall (stoop and room) method. In some cases, however, it is successfully worked on the Longwall system. For blast shale, gunpowder is the explosive used, the cost per ton of shale being 3·16*d.* for gunpowder and 0·27*d.* for fuse. Fire-damp occurs in shale workings though not in great volumes; and shale sealing being of good thickness the airways are of comparatively large area which contributes materially to the maintenance of good ventilation. The quantity of water met with in ordinary working is not great. At the new openings at Duddingston haulage from the inclined shafts is effected by electricity. The importance of the oil-shale industry in Scotland is shown by the fact that in 1904 a total of 2,332,000 tons was mined, yielding 62,932,000 gallons of crude oil from which was produced 2,517,000 gallons of naphtha, 17,000 gallons of illuminating oil, 38,000 tons of gas oil, 39,500 tons of lubricating oil, 22,500 tons of wax and 49,600 tons of sulphate of ammonia.

B. H. I.

Slate Industry of the United States. T. NELSON DALE.

(Bulletin of the United States Geological Survey. No. 275. Washington, 1906.)

This monograph, which covers 154 pages, with 25 plates and illustrations in the text, deals with the origin, composition and structure of slate in general, and the slate deposits of the United States in particular. A bibliography of slate and a glossary of geological and slate-quarrying terms are appended.

The following is the classification of slates adopted by the Author:—

I. Aqueous sedimentary:—

- A. Clay slates: Matrix without any or with but very faint aggregate polarization (Martinsburg, West Virginia).
- B. Mica slates: Matrix with marked aggregate polarization.
 1. Fading: With sufficient iron carbonate to discolour on prolonged exposure.
 - (a) Carbonaceous or graphitic (Lehigh and Northampton counties, Pennsylvania, Benson, Virginia).
 - (b) Chloritic, greenish (sea-green Vermont).
 - (c) Hematitic and chloritic, purplish (Pawlet and Poultney, Vermont).
 2. Unfading: Without sufficient iron carbonate to discolour on prolonged exposure.
 - (a) Graphitic (Peach Blossom, Pennsylvania and Maryland; Arvon, Virginia; Northfield, Vermont; Brownville, Maine).
 - (b) Hematitic, reddish (Granville, New York; Polk county, Arkansas).
 - (c) Chloritic, greenish (unfading green Vermont).
 - (d) Hematitic and chloritic, purplish (Fairhaven, Vermont; Ticonderoga, New York).

II. Igneous:—

- A. Ash slates.
- B. Dyke slates.

The scientific basis for these subdivisions is explained, and microscopic and chemical analyses of the slates are given. The difficulties in slate-quarrying are many. The cost of slate at some quarries is increased by the necessity of removing the waste-heaps of former working which, for lack of capital or of good judgment, were placed on valuable slate. There are also uncertainties of a stratigraphical character which the use of a core-drill would eliminate. The percentage of waste is generally high. In the Peach Blossom region it is as much as 88 per cent. In the Maine quarries it is also considerable, owing to the frequent interbedding of the slate with quartzite. In 1904 the United States produced 1,233,757 squares of roofing-slate, valued at £933,858, and £189,581 worth of slate for purposes other than roofing. The relative commercial value of several slates is an index of their physical characteristics. The following were the prices in dollars ruling in January, 1905, per square for slates No. 1 quality, 16 inches by 8 inches:—Peach Blossom 6·35; Monson, Maine 7·20; red New York 11; unfading green Vermont 4·50 to 5·25; sea-green Vermont 3·50; and Virginia 5 to 5·50.

B. H. B.

Floating a Wrecked Ship by Compressed-Air.

(Engineering Record, New York, 15 December, 1906, pp. 672-3.)

A large steamer of 12,000 tons, the "Bavarian," belonging to the Royal Mail Line, sunk in the St. Lawrence, was successfully raised by the unusual method of employing compressed-air to force the water out of the damaged compartments. Other plans which were tried failed, the holes being too large to patch, so that pumping was impossible. All the compartments were made as tight as practicable, and the hatches were closed by plating, while air-locks were placed on the compartments which had filled. As the air was forced in, the water receded, and workmen were able to stop the leaks with temporary plating. An unusually high tide being expected on the 16th November, 1906, advantage was taken, in spite of a gale, to exert the full power of the compressor-plant as the tide rose, and the ship, having been lifted from the rocks and floated clear, was towed to Quebec and was beached for repairs.

C. O. B.

Berlin Waterworks. G. ANKLAM.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, Brunswick, vol. xxxviii, part iii, 1906, pp. 589-608.)

The Author begins his description with a summary of the gradual growth of the Berlin Waterworks to the present time, and of the precautions taken for future extensions. He describes more

particularly the conversion of the former lake-water to ground-water supplies, dealing with the methods of estimating the quantity and the deferrization-works at Tegel and Muggelsee. The average analysis of the ground-water in these neighbourhoods gave the following results:—

Residue at 120° C.	17·00	grains per gallon.
Chlorine (Cl)	0·40	" " "
Ammonia (NH ₃)	0·02	" " "
Iron (Fe)	0·08	" " "
Sulphuric acid (SO ₂)	1·18	" " "
Nitrates	0·00	" " "
Nitrites	0·00	" " "
Oxygen absorbed expressed in KMnO ₄	0·27	" " "
Total hardness	9·8	German degrees.
Permanent hardness	2·2	" "
Temperature	10° C.	" "

The careful examination of the underground conditions proved that it would be possible to draw a supply of 770 gallons per second, completely replacing the former supplies. At Tegel two long galleries of a total length of 2·25 miles, containing 118 tube-wells delivering 1·5–2·5 gallons per second, have been constructed, whilst at Muggelsee there are three such galleries, 6 miles in length, containing 350 tubes, delivering 1·5–1·75 gallons per second. The old pumping-stations have been reconstructed and the water is lifted to pass over the deferrizing-sprinklers. The construction of these latter works is similar to a scrubber for gasworks. The entire construction is of wood. The water is distributed by means of main and secondary sprinkling-channels, and trickles downwards over a series of wooden shutters, depositing the iron in form of iron oxide due to the aeration on the shutters. The apparatus is fitted with wooden valves and sluices so that it can be flushed by regulating the intensity of distribution. The water is afterwards passed through the old sand-filters to remove finally any suspended matter or iron contained.

The article is accompanied by numerous illustrations, drawings and statistical tables.

F. R. D.

Lowering 500 Feet of 36-Inch Water-Main.

(Engineering Record, New York, 15 September, 1906, p. 297.)

To accommodate street lowering in Bronx, New York City, it was necessary to lower, with the least possible interruption to service, a main having, in the 500 feet to be dealt with, a vertical curve with a versed sine of 2 feet. This had to be lowered 5 feet with even grades replacing the curve. After the main was exposed, 3-foot trenches were opened on each side of the pipe which was then cut under except at the joints, 12 feet apart. The centre of each length of pipe was then supported by wooden cribbing and the joints were cut under. By means of four 10-ton jacks, set as closely as possible to

the cribbing, the latter was released, and the pipe lowered a maximum of 2 inches at the centre of the five-length portion under treatment. The jacks were then worked very carefully so that their amount should be distributed between all of the six joints affected, thus reducing the movement in each joint to a uniform amount of $\frac{1}{4}$ inch, and flattening the original curve. This operation was then repeated under the remaining lengths. When the main had thus been reduced from a curve to a uniform gradient the jacks were employed at one end in lowering the pipe bodily as before in six-length portions successively from one end to the other, and in travelling backwards and forwards they effected a depression of 2 to 3 inches at each trip. When the clearance for the jacks became insufficient wheel-derricks were used. The trenching was begun on the 18th July, and water was shut off at 6 A.M. on the 26th August, when the lowering was commenced; and it was finished at 5 P.M. on the same day, with twenty-five men.

C. O. B.

Dresden Sewerage-Works. KLETTE.

(Deutsche Bauzeitung, Berlin, 1906, 18 August, pp. 443-7; 1 September, pp. 467-72; 22 September, pp. 511-6; 3 October, pp. 531-5.)

The Author prefaces his description of the new sewerage-works commenced in 1890 by an historical retrospect of the older systems and their defects in the city of Dresden.

The new system has been laid out on deep-drainage principles, no sewers having a less depth than 10 feet at their upper ends, whilst the lower sections have often been laid at depths of 23-26 and even 39 feet. The drainage-area covers nearly 17,000 acres, which is subdivided into twelve secondary areas, each with its system of main and branch sewers discharging its sewage into main trunk interceptors on either side of the River Elbe. The grades have been so regulated that the minimum velocity should be at least 2 feet per second. For calculating the maximum flow of water to be discharged a rain of 0.7 inch per hour has been accepted, and on this basis, in consideration of the four categories of density of building, the following quantities have been determined:—

- | | |
|---|--------------------------------------|
| (1) For the old town densely built on . . . | 0.71 cubic foot per acre per second. |
| (2) Densely built on, but less than (1) . . . | 0.57 " " " " " " |
| (3) Open building | 0.43 " " " " " " |
| (4) Parks, gardens, etc. | 0.03-0.21 " " " " " " |

The dirty-water flow has been determined on the basis of a water-supply of 37.5 gallons per head per day, and in consideration of the three factors of density of population:—

- | | |
|------------------------------|---------------------------------------|
| (1) 450 persons per acre, or | 0.047 cubic foot per acre per second. |
| (2) 305 " " " " " | 0.033 " " " " " " |
| (3) 49 " " " " " | 0.005 " " " " " " |

The sewerage system has a total discharging-capacity of about

5,600,000 cubic feet per second, and the main interceptors have a combined capacity of 425,000 cubic feet per second, allowing a dilution of four to five times the dirty-water flow, and discharging all surplus water as storm-water into the river.

The whole system has been executed in concrete; the small sewers are egg-shaped in the ratio of 2:3 of breadth to height; the large sewers are bell-mouthed, and where it was necessary, special inverts have been constructed to carry off the dirty water. The 30 miles of new sewers have cost £425,000.

The Government permitted the simplest form of purification of the sewage, viz., screening and sedimentation to remove all suspended matters of more than $\frac{1}{4}$ -inch in size, and the provision of means for disinfection in case of epidemics. The analyses of the River Elbe justified such simple treatment, for they showed that the ordinary dry-weather flow of the river contained 14 grains per gallon of suspended and polluting matter, and the estimated increase due to the sewage would only be 3.5 grains per gallon.

The article is accompanied by numerous illustrations showing types of sewers, methods of construction and flushing and the purification-works.

F. R. D.

Dessau Vertical Retort. Dr. J. BUEB.

(*Journal für Gasbeleuchtung*, Munich, 30 June, 1906, pp. 553-9.)

Since the last report on the working of these vertical retort-settings¹ great improvement has been effected by the introduction of steam into the retort, the yield of gas has been increased, and the deposition of retort carbon is almost completely prevented. The Author is now able to state that by carbonizing with vertical retorts, as installed at Dessau and Mariendorf, a ton of average coal will yield 12,588 cubic feet of gas, having a gross calorific value of 562 B.Th.U. per cubic foot.

It is evident that steam could be added to such an extent that by the production of water-gas the total yield of gas would be considerably increased; the coke, however, would lose its value as a fuel. It has been decided, therefore, to produce a gas with a heating capacity of not less than 562 B.Th.U. per cubic foot, and this may be done without any deterioration in the quantity or quality of the coke produced.

A series of experiments have been conducted in order to study the quantities of gases evolved from coal carbonized in vertical retorts during the period of distillation. Four retorts were employed for these experiments, and the coal used was in one case an English New Levenson coal, and in the other a Westphalian coal, Mont Cenis.

The following Table shows the results obtained from a charge of 2,000 kilograms (1.97 ton) of the English New Levenson coal:—

¹ See Minutes of Proceedings Inst. C.E., vol. clxiii, p. 429.

Period of Distillation.	Yield of Gas.		Illuminating Power in Batswing Burner. Consumption 5.3 Cubic Feet Hourly.		Caloric Power (16° C. and 768 Millimetres).		Ammonia.		Cyanogen.		Specific Gravity of Purified Gas.
	Cubic Feet.	Percentage of Total Yield.	Illumina in Power.	Percentage of Total Yield.	B.Th. U. per Cubic Foot.	Percentage of Total Yield.	Grammes per 100 Cubic Feet.	Percentage of Total Yield.	Grammes per 100 Cubic Feet.	Percentage of Total Yield.	
Hours.			Candles.								
1	2,614	11.5	21.05	19.1	766	14.6	35.47	14.6	9.90	8.2	0.48
2	2,331	10.3	16.57	13.4	677	11.7	36.46	13.3	13.25	9.1	0.45
3	2,260	10.0	16.13	12.7	637	10.7	39.60	15.0	14.60	10.4	0.43
4	2,048	9.1	14.64	10.4	625	9.7	35.67	11.5	15.57	10.1	0.42
5	1,978	8.7	14.03	9.6	601	8.8	33.40	10.4	14.60	9.1	0.41
6	1,978	8.7	12.80	8.8	588	8.7	27.18	8.5	17.04	10.7	0.40
7	1,907	8.4	11.14	7.4	569	8.0	23.95	7.2	17.66	10.7	0.40
8	1,837	8.1	10.96	5.5	562	7.7	21.03	6.1	15.96	9.4	0.39
9	1,872	8.2	9.30	6.0	549	7.4	16.70	4.9	14.66	8.7	0.37
10	1,801	7.9	7.89	4.9	475	6.4	15.71	4.4	11.77	6.7	0.35
11	1,413	6.2	4.47	2.2	433	4.5	13.25	2.9	11.04	5.0	0.31
12	635	2.9	Nil	..	376	1.8	11.97	1.2	5.83	1.9	0.27

The experiments show that carbonization in vertical retorts is essentially different from that in horizontal or inclined retorts. The hourly yield of gas is much more uniform, and is practically constant until the last hour of carbonization; with horizontal retorts, however, a considerably higher percentage yield of gas takes place during the first half of the distillation period. Again, the illuminating and calorific powers of the gas produced, as also the yield of ammonia, are relatively higher from coal distilled in vertical retorts. The production of cyanogen is lower, amounting to only 60 per cent. of that obtained by carbonizing in horizontal retorts. 4

The results obtained in these experiments have already been surpassed in practical working.

The Author feels in a position to state that the life of vertical retorts and settings is longer than that of horizontal.

The cost of installation of vertical retorts is practically the same as that of inclined retorts, compared on the basis of equal gas production. With vertical retorts, however, the ground space is better utilized, and thus a smaller retort-house is constructed, and the coal and coke conveying-plant is smaller. These items reduce the total cost of erection of a retort-house of vertical retorts compared with one of inclined retorts of equal working capacity.

E. V. E.

Electricity in Warfare. ALFONS SPAČIL.

(Mitteilungen über Gegenstände des Artillerie- und Geniewesens, Vienna, 1906, vol. x, pp. 758-78.)

This is an article dealing with the adaptability and possibilities of electricity as an illuminating agent for general war purposes and more particularly for special uses, such as signalling and searchlight work. The tactical advantages of field, stationary and coast-defence searchlights are fully investigated, and their mode of operation, transportation, range and mobility are discussed.

Various forms of portable generating-sets for supplying electrical energy (self-propelled or drawn by horses, etc.), cable-cars and searchlight-carriages and mountings (sectional or otherwise) are described, and deductions are drawn as to their possibilities under various service conditions. Standardization is recommended for searchlights with mirrors up to 90 centimetres (about 3 feet) in diameter, and details are given as to personnel, cost and spares required for each set.

C. J. G.

Direct Compensation of Armature-Reaction in Alternators.

A. HEYLAND.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 81-3.)

The Author describes in this Paper a simple and direct method of compensating the armature-reaction in alternators, which is not open to the objection, urged against other methods, of requiring auxiliary apparatus whose cost may counterbalance the economy otherwise obtained. The method consists in giving different values to the air-gaps of the poles of opposite polarity of the alternator and of the exciter—that is, a larger air-gap for, say, north poles than for south poles—and to reduce, in a corresponding manner, the number of turns of the field-coil of those poles which have the smaller air-gap. This modification may easily be made, and it gives an economy of copper on half the poles and increases the quality and stability of the machine. When this dissymmetry has been introduced and excitation established, the latter may by chance be in the wrong direction. If so, the compensation acts negatively, and the machine shows very strong armature-reaction; in that case the excitation need only be reversed and no other trial is necessary. The Author discusses the principle which has led him to adopt this method.

W. C. H.

Manufacture of Carbons for Electrical Purposes. J. ESCARD.

(L'Éclairage Électrique, Paris, 1906, vol. xlviii, pp. 363-71.)

The development of electrical science as applied to industry early made it necessary to find a means of producing artificially carbons suitable for the various purposes for which they are required. The Author of this article gives a brief account of the history of this subject, and then describes some processes used to-day in the manufacture of carbons. These carbons may be classified according to the special purpose in view, as follows:—(1) Carbons for arc-lamps; (2) brushes for generators; (3) carbons for use in electrolytic processes; (4) carbons for such types of apparatus as lightning-arresters, and for heating-resistances; and (5) carbons for various purposes and manufactured in the form of bars, plates, cylinders, tubes, and pencils of small diameter. In the early portion of the Paper the Author describes the process of manufacture invented by Jacquelin in 1882, and since then perfected by him, which aims at producing a carbon of higher conductivity than calcined wood charcoal and free from all impurities. Three different methods of treatment for the purification of the carbon are used in this process—the carbon being treated either with chlorine at high temperature, with fused caustic soda, or with hydrofluoric acid at ordinary

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temperature. All three processes are discussed by the Author. The carbons used at the present time are formed of a paste, of which the basis is retort-carbon carefully selected and freed from impurities; it is powdered and mixed under heat with pitch to make a homogeneous paste, then subjected to high pressure and forced out in rods through holes, of which the dimensions may be varied according to the desired result. The rods are then cooked for a long time at a temperature of $1,600^{\circ}\text{C}$.

Brush-carbons must be of very fine grain in order to avoid wear of the commutators and they must have high conductivity. They are therefore made in separate dense and homogeneous blocks, which are afterwards compressed hydraulically and then cut into segments of suitable size and shape.

The use of graphitic carbons has increased rapidly in recent years, and the Author describes two processes of manufacture. The first, invented by Girard and Street, consists in making bars of amorphous carbon pass through a closed vessel, where, in their passage, they are subjected to an electric arc and transformed into graphite, being afterwards broken up into fragments to be used in the manufacture of carbons for different purposes. In the second process, invented by Acheson, the amorphous carbon—in the form of coke—is transformed into graphite by mixing it with sand and other suitable materials and subjecting the whole to the high temperature of the electric furnace.

W. C. H.

New Type of Electric Condenser for Commercial use.

C. F. GUILBERT.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 208-19.)

Two years ago Mr. Moscicki showed that the difficulty of constructing condensers suitable for industrial purposes lay not only in the nature of the substances used as dielectrics, but also in the plane-shape which has hitherto been given to them, as the density of the lines of force is increased near the edges of the dielectric, and perforations occur there in consequence. In this article the Author describes the new commercial condenser which Mr. Moscicki has now perfected. The dielectric is a long round glass tube, closed at the bottom and open but narrow at the neck, and having the walls of the neck three or four times thicker than the rest of the tube. An extremely thin layer of silver-plating, deposited chemically, covers the inside and outside of the tube, and this is itself covered with a much thicker layer of copper, which gives it the necessary consistency. With this arrangement the dielectric is strengthened at the edge of the outer armature, and the element has the same resistance to the tension as if the tube were all of the thickness of the neck, while its capacity is determined by the thickness of the tube.

Each tube has a terminal fixed in the neck and connected to the internal armature, and the neck is itself sealed into a fluted insulator giving excellent insulation between the two armatures. The glass tube is then placed up to the neck inside a brass or iron tube, of which the mouth is hermetically sealed by a conical plug of caoutchouc. The space between the two tubes is filled with a mixture of distilled water and glycerine; by this means the heat is distributed through the whole mass, and local heating, which would lead to rupture, is prevented; further, instead of having the polished copper as cooling-surface, one has the whole outer surface of the surrounding tube, which is blackened to promote radiation.

These condenser elements are ordinarily used for tensions of 10,000 volts to 15,000 volts, and are tested to 27,000 volts to 40,000 volts in course of manufacture. The tubes are about 1.6 inch in diameter and about 21 inches to 53 inches long. For use with lower tensions a self-induction coil may be used in series with the condenser, or the condenser may be put in the secondary of a step-up transformer, of which the primary takes the usual place of the condenser in the main circuit. Even with these auxiliaries the cost of the apparatus is not unduly increased: without them, the cost per kilowatt-ampere is low. The Author gives examples of their use.

W. C. H.

Constant Direct-Current Dynamo. E. ROSENBERG.

(Electrical World, New York, 1906, vol. xlviii, pp. 918-21.)

The Author describes the construction and the field of application of a new type of direct-current dynamo which he has invented. The main feature of the machine is that it gives a current of practically constant strength throughout a wide range of armature-speed. The brushes, which occupy the position of the main brushes in an ordinary dynamo, are here short-circuited, and merely serve to produce a cross-field at right angles to the main field. The motion through this cross-field produces the useful electromotive force in the armature, and the current for the outside circuit is collected by brushes displaced from the auxiliary brushes by half the polar distance. The field may be excited either separately or in series with the armature current. The Author discusses the characteristics of the machine and the field of application for which it is specially suited. It has found extensive application in the lighting of trains, the dynamo being usually driven from the car-axle by belts. It is also suitable for use in arc-lamp lighting, in welding, and as an automatic booster.

W. C. H.

Electrical Ignition in Internal-Combustion Engines.

F. W. SPRINGER.

(Electrical World, New York, 1906, vol. xlviii, pp. 995-8, 1111-5, and 1242-3.)

There are two kinds of spark used for electrical ignition in internal-combustion engines—the contact-spark, where con-
 tion is made between the spark-points for a definite part
 a revolution and is then broken, so as to draw an arc of $\frac{1}{16}$
 $\frac{5}{16}$ inch in length, and the jump-spark, where use is made gener-
 of a vibrating induction-coil. In this article the Author investig-
 the phenomena in ignition by each of these means and determ-
 from theoretical considerations and practical tests the best feat-
 to be embodied in such apparatus. For a contact-spark induct-
 coil the core should be of soft iron wire, of high permeability
 small hysteresis, and should be annealed by heating to red heat
 piece of gas-pipe and allowing it to cool very slowly. The wires sh-
 be as thin as possible, and should be varnished or coated with sh-
 before they are assembled. The length of the core may be 4-
 7 times the diameter. A high-resistance coil should have a si-
 core of relatively large diameter, and should be wound with a la-
 number of turns of fine wire. A low-resistance coil should hav-
 long core of large diameter and a large ratio of length to c-
 diameter, and the winding should consist of a few turns of co-
 wire sufficient in number to give the desired self-induction.

The jump-spark is electrically very inefficient, but it has ad-
 vantages over the contact-spark in that it has much greater disrupt-
 and detonative qualities, and is therefore more effective; the igni-
 lag is usually less, the ignition-point is more easily shifted, and t-
 is usually less noise. For this spark also, the primary building-
 curve is very efficient in storing magnetic energy in the core.
 efficiency of jump-spark coils could be improved by giving them
 following features:—A small iron core of fine insulated wire; a l-
 resistance primary and a relatively low-resistance secondary coil
 exceedingly quick hammer-break vibrator, hitting the core at
 same time as it makes the break; a vibrator which does
 “chatter”; a small mica primary condenser; a high primary vol-
 with low-resistance batteries; a short time of contact in the eng-
 timer, resulting in only one or two sparks for each explosion.
 jump-spark coils the source of current must have greater curr-
 capacity than for contact-coils, on account of the lower efficiency
 greater number of sparks. The voltage should be constant.
 concluding portion of the article gives a large number of cu-
 showing instantaneous values, as measured by the Duddell osc-
 graph, of the primary and secondary currents of different jump-sp-
 is, and two Tables containing the values of the important fac-
 each coil and the data of the tests.

W. C. F.

Photometric Standards of Light. DR. E. LIEBENTHAL.

(Journal für Gasbeleuchtung, Munich, 30 June, 1906, pp. 559-61.)

At the 1903 meeting of the International Committee on Photometry at Zürich it was decided to carry out comparative tests of the various standards of light existing in Germany, France and England (the Hefner, Carcel and Harcourt lamps). This work has been executed in the German Reichsanstalt, and a large number of comparisons have been made against the constant light of an incandescent electric lamp.

The flame of the Harcourt 10-candle-power pentane lamp attains almost a constant height after having been lighted 10 minutes, and in this way requires much less attention than the 1-candle Hefner lamp. Of these two lamps, however, the Harcourt is more sensitive to a change in the air of the laboratory, it having decreased about 2 per cent. in luminous intensity during the first 20 minutes.

The tests were undertaken with German as well as English standard pentane, which were found to give similar results.

As a result of forty-seven comparative tests with English and German pentane it was found that the light of the Harcourt pentane lamp was equal to 11 Hefner candles; the air of the room contained 8.8 litres of aqueous vapour per cubic metre of dry air, and the barometric pressure was 760 millimetres.

At the National Physical Laboratory in London the standard light is obtained with the Harcourt 10-candle-power lamp burning in an atmosphere of 10 litres of water-vapour per cubic metre of dry air, this being the average condition prevailing in London. The Author states that with these conditions the 10-candle pentane lamp is equal to 10.9 Hefner candles.

In the case of the Carcel lamp it was found that with 8.8 litres of aqueous vapour per cubic metre of dry air the light obtained was equal to 10.8 Hefner candles.

The Harcourt lamp gave results which varied on an average ± 1.1 per cent. from the mean reading, the greatest deviation being 2.2 per cent.; whilst the variation with the Carcel lamp was ± 1.8 per cent. and the greatest deviation 4.6 per cent. The Carcel lamp, therefore, cannot give accurate results.

E. V. E.

Relative Value of the Carcel, Hefner and Vernon-Harcourt Standards of Light. PEROT and LAPORTE.

(Comptes Rendus de l'Académie des Sciences, Paris, 1906, vol. cxliii, pp. 743-4.)

The Authors have made measurements to determine the exact relation to one another of the values of the different standard flames. The mean of the results obtained by two methods of observation, one direct, one indirect, is shown in the following Table:—

		Value of Lamp.		
		Carcel.	Vernon-Harcourt.	Hefner.
In	Carcel	1·0	1·004	0·0930
	Vernon-Harcourt . . .	0·996	1·0	0·0931
	Hefner	10·75	10·74	1·0

These tests show the difficulty of employing a flame-standard, and emphasize the desirability of having a standard based on a physical phenomenon as independent of external conditions as possible, such as, for example, the Violle standard.

W. C. H.

Metallic Arcs. I. LADOFF.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 281-84 and 361-3.)

In this article the Author discusses the behaviour and efficiency of different types of electric arc-lamp, noting the points in which the ordinary carbon arc is imperfect and comparing the results obtained with impregnated carbons and with metallic arcs. In the earlier portion of the article the physical conditions existing in the arc and at the junctions of the electrodes with the intervening gas are considered theoretically and in the light of different researches, and the Author then goes on to describe the results he has obtained with a new lamp, using as electrode an alloy of titanium with a good conducting metal such as copper or iron. Titanium itself is the best substance for an arc-electrode from the point of view of luminosity, but it is a bad conductor and can therefore only be advantageously used in combination with bodies of high conductivity. Difficulty was found in making the alloys, but this was finally overcome. A Table is given showing the results of comparative tests made on three lamps having negative electrodes respectively of the following constitution:—(1) 80 per cent. of ferro-titanium; (2) 30 per cent. of titanium-oxide, 70 per cent. of magnetite; (3) homogeneous carbon $\frac{1}{2}$ inch in diameter.

The positive electrode was generally of carbon, but tests were also made with a copper electrode, which gave somewhat lower luminosity. The figures in the Table are mean values for all the tests, and show very high photometric values and efficiency for the ferro-titanium lamp and also for the lamp with oxides. The latter are not so high as in the case of the first lamp, but are much higher than those for the carbon lamp. The life of the electrode is also shown, and is longest for the lamp with oxides and shortest for the carbon lamp. Another Table gives the results of similar tests on a lamp with oxides, using: (1) negative carbon electrode above,

positive oxides below; (2) positive carbon above, negative oxides below; (3) oxides in both electrodes, the upper being positive. The last shows very high luminosity and efficiency. Other tests are also described.

The arc from ferro-titanium or titanium-oxide electrodes is white in colour. With pressures above 70 volts the arc is unstable and easily breaks. For a pressure of 50 to 55 volts the length of the arc is about $\frac{1}{2}$ inch, and $\frac{3}{4}$ inch to 1 inch for a pressure of 70 volts.

W. C. H.

Measurements on Temperature and Selective Radiation of Incandescent Lamps. C. W. WAIDNER and G. K. BURGESS.

(Electrical World, New York, 1906, vol. xlviii, pp. 915-7.)

The Authors have made investigations to determine whether the high efficiency obtained with some recent metal-filament lamps is to be attributed to selective radiation or to a higher working temperature of the filament or to both. Measurements were made with tungsten, tantalum, and carbon-filament lamps. A diagram and description are given of the arrangement of apparatus for the temperature measurements, in which the Holborn-Kurlbaum optical pyrometer was used, and the results of all the measurements are set out in tables. These show that tantalum is more selective in its radiation than tungsten, and in all probability would be more efficient than tungsten at the same true temperature. The higher efficiency of the tungsten lamp must therefore be due to the much higher temperature at which the tungsten can be worked continuously. Similarly the increase in efficiency shown by both tungsten and tantalum lamps over the carbon lamp is to some extent due to selective radiation, but is rendered possible to a greater extent by the fact that they can be operated at a higher working temperature. The high efficiency of these metal-filament lamps compared with that of the arc lamps, where the temperature of the luminous source is more than $1,500^{\circ}\text{C}$. ($2,732^{\circ}\text{F}$.) higher, is not at variance with this conclusion, as the loss of power in the arc is readily explained by the conduction and radiation of the carbons and by convection currents.

W. C. H.

Osram Glow-Lamp.

(Teknisk Ugeblad, Christiania, 1906, pp. 354-6.)

The name of this lamp is coined from the alloy of osmium and wolfram, of which the incandescent wire is made. The wire is only 0.03 millimetre (0.0012 inch) in diameter, and glows in a highly

rarefied vacuum. On the scale of charges of the Christiania electricity-works for private houses an osram lamp of 25 candle-power will cost about the same as a corresponding petroleum lamp, namely about 2 øre (0.27d., say one farthing) per hour. A 1-watt lamp will cost only one-third as much, rendering the electric light far cheaper than petroleum. The new lamps are already being made of 25 and 32 and 50 candle-power, with 100 to 130 volts; they take about 1 watt per candle-power. At present they have to hang vertically, but will doubtless be made to burn in any position. The luminosity and the consumption of electricity are both alike approximately constant during the whole life of the lamp. In official trials of eight lamps of 32 candle-power and eight of 25, the intensity of the light increased during the first 200 hours, and afterwards diminished slowly to 30.7 and 26.7 respectively after burning 1,000 hours. Meanwhile the consumption averaged 1.05 to 1.16 watt per candle-power, against three to four times as much in a carbon-fibre lamp. Either direct or alternate current may be used.

A. B.

Osram Lamp.

(Elektrotechnische Zeitschrift, Berlin, 9 August, 1906, pp. 749-51.)

This lamp, manufactured by the Deutsche Gasglühlicht Aktien-Gesellschaft, of Berlin, was exhibited for the first time in May last before technical societies at Stuttgart and Lindau, before being placed on the market. According to efficiency and endurance tests made by the Physikalisch Technische Reichsanstalt on a number of these lamps, the average loss of candle-power after 1,000 hours was 6.3 per cent. in a 25 candle-power Hefner lamp, and 3.6 per cent. in a 32 candle-power Hefner lamp, with a maximum loss in the case of individual lamps of 11.4 per cent. and 6.1 per cent. respectively.

The average consumption during this period rose from 1.10 to 1.17 watt per Hefner candle at the end of 200 hours.

Details of running costs are given, and a number of curves, illustrating the properties of the lamp, are shown.

C. J. G.

Electricity-Meter for Variable Tariff. DE KERMOND.

(L'Electricien, Paris, 1906, vol. xxxii, pp. 97-100.)

This Paper describes an electricity-meter with a special mechanism attached which indicates automatically the total sum of money due from the consumer. The mechanism allows of as many as seven different rates of cost per kilowatt-hour being applied, according to the hour of the day at which current is used, or even according to

the season of the year. By this system of varying rates, consumers are encouraged to use current at hours of light load, and the station derives a benefit. The spindle of the brake-disk of an ordinary integrating-meter is fitted with a worm which drives a wheel having teeth of different sizes. This wheel A drives another wheel B, which in its turn drives the recording train of wheels; but B is mounted on the end of a movable lever, and its revolutions depend on its position with regard to A, the number of teeth of A engaging with the teeth of B for one revolution of A varying as the position of the lever changes. The lever, pivoted at the top, rests about the centre of its length on one or other of three tariff-disks which make one complete revolution in 24 hours, and have their periphery so cut as to modify, according to the time of day, the position of the lever, and consequently the position of the wheel B. By means of a worm the tariff-disks may be displaced with relation to the lever, so that different tariffs may be obtained for different seasons of the year. As the recording wheels are driven by B, it will be seen that for an equal consumption of energy the pointers on the dials will revolve more or less rapidly according as the wheel B occupies one position or another with regard to its driving-wheel A, that is, according as one or several teeth of A engage with B on each revolution. Thus, for each displacement of the lever and of the wheel B, a new tariff comes into play. The mechanism is driven by a pendulum which goes for 40 days without being re-wound. On the front of the box of the instrument there are openings, behind which indicators appear showing the hour and minute of the day, and the number of watt-hours consumed. In addition there are dials showing the total sum of money due by the consumer. The Author gives diagrams of the apparatus and illustrations showing the complete mechanism in its case. The apparatus has been successfully applied by the municipality of Lausanne, to the complete satisfaction of the consumers and of the undertakers.

W. C. H.

Alternating-Current D'Arsonval Galvanometer.

W. S. FRANKLIN and L. A. FREUDENBERGER.

(Electrical World, New York, 1906, vol. xlviii, p. 562.)

The Authors have devised a galvanometer of the D'Arsonval type for use with alternating currents, which is for equal strengths of field as sensitive as the direct-current instrument. The electro-magnet has a laminated core, and is excited from alternating-current mains through an adjustable choking-coil and condenser, so that the alternating magnetic flux is substantially in phase with the electromotive force of the mains. This flux, traversing the movable coil, induces in it an alternating electromotive force, which, when the circuit of this coil is closed externally, gives rise to a

secondary current, and thereby a unidirectional pulsating torque is set up on the coil, even though no current is applied to it from an external source. By means of an adjustable external resistance the coil is allowed to assume a definite position of equilibrium under this torque, and then the alternating current to be measured is superposed upon the secondary current, and a measurable deflection is produced.

W. C. H.

Single-Phase Induction-Motor. A. STILL.

(Electrical World, New York, 1906, vol. xlviii, pp. 1106, 1152 and 1203.)

In three articles on the single-phase induction-motor the Author explains the fundamental principles of action of this type of machine. The explanation is given without reference to a resultant rotating magnetic field, the motor being considered as an alternating-current transformer with a divided core and movable secondary winding. The opening sections of the discussion are therefore devoted to an analysis of the operation of the simple stationary transformer, and thereafter the single-phase motor is considered from this point of view, and by means of vector-analysis its characteristics and properties are developed. The final article deals with starting devices, describing especially in this connection the Heyland motor, and giving the starting torque obtainable with it. A Table is given showing the efficiencies at full load and half-load, and the power-factor at full load, of single-phase motors ranging between 5 and 50 HP. working on a frequency of 50; and the article concludes with a short discussion of speed-regulation, and some comparisons between the single-phase and the polyphase motor.

W. C. H.

Tractive Effort of Single-Phase Commutator-Motor Equipment.

B. G. BERGMAN.

(Electrical World, New York, 1906, vol. xlviii, pp. 713-4.)

One of the objections to the use of the single-phase commutator-motor for traction purposes, and especially for heavy traction with locomotives, is the effect of the pulsating torque. The Author discusses the effect of this pulsation on the tractive effort of such motors, and shows that while theoretically the maximum useful pull must be lower with an alternating than with a direct-current equipment, the cause of this lower maximum useful pull may in fact be eliminated by the elasticity in the different parts transmitting the pulsating forces. Tests are described, from which, along with the theoretical discussion, the Author concludes that a 25-cycle

alternating-current equipment with geared motors, connected with the wheels in the standard way, has a maximum tractive effort about 15 per cent. less than that of a direct-current equipment; that with gearless motors, having armatures rigidly connected to the wheel-axes, the results would be still worse; but that with either geared or gearless motors the alternating-current equipment can be made to exert as high a tractive effort as a direct-current equipment by introducing sufficient elasticity somewhere between the armature of the motor and the rim of the wheel. A rather slight flexibility is sufficient, and therefore perfectly reliable devices may be designed for this purpose.

W. C. H.

Motor-Truck for Difficult Transport Work.

(Electrical World, New York, 1906, vol. xlviil, pp. 808-9.)

A huge telescope with a lens of 60 inches diameter has been constructed for the Solar Observatory of the Carnegie Institute, Washington, which is situated on the top of Mount Wilson, near Pasadena, and in order to move the apparatus from the shops to the Observatory—a distance of 9 miles with a rise of 5,000 feet, and part of the way consisting of a steep mountain path with many sharp turns—a special motor-truck has been designed and constructed. In the front portion of the truck there is placed a 40-HP. petrol-motor, connected directly to an electric dynamo supplying current to the driving-motors. The truck has four wheels, and inside each there is mounted a 4-HP. electric motor, but designed for heavy overload. The armature-shaft is in a horizontal position nearly at right-angles to the axis of the wheel but slightly out of the horizontal plane, and pinions at both ends of the shaft engage circular racks on both of the inner walls of the wheel so as to apply a torque at each end of the shaft forcing the rear portion of the wheel upward and the front portion downward, when the truck is moving forward. The steering-gear operates both front and rear wheels simultaneously, turning the two pairs through opposite but corresponding angles and thus enabling the truck to go round sharp turns on the mountain roadway. In going down-hill the motors are driven as generators and act as a brake, special resistances being provided for regulation. Each load of the truck will weigh about 5 tons, and with this load the truck is expected to give on the steep gradient to the mountain-top a speed of 2 miles per hour, and on the level about 12 miles per hour.

W. C. H.

Physical Meaning of Power-Factor, and Significance of a Power-Factor less than Unity without Phase-Difference.

ALBERT F. GANZ.

(Journal of the Franklin Institute, Philadelphia, December, 1906, p. 429.)

The Author begins with the simple case when the amperes and the volts in an alternating current follow a true sine-wave, and he shows analytically and graphically that when the amperes and the volts are in phase the power-factor is unity, and when the phase-difference is 90° the power-factor is zero. In every case the power-factor curve is a sine-curve of twice the frequency of either the ampere- or the volt-curve, and the physical meaning of this curve is that positive values mean work done by the dynamo on the circuit and negative values work done by the circuit on the dynamo. When the curve is equally placed about the axis of the ampere and volt-curves the positive values are equal to the negative values; this occurs when the amperes and volts are in quadrature, the power-factor is then zero; that is, the current is wattless.

The Author then proceeds to consider the case in which the wave-forms are not sinusoidal, and he obtains an expression for the power-factor by means of the Fourier theorem. He deduces from this expression that the power-factor is unity in all cases when the circuit has a constant resistance and zero-reactance, no matter how irregular the applied electromotive-force wave may be. If, on the other hand, the electromotive-force and current waves have different harmonics the power-factor will be less than unity. A common example of such irregular waves occurs with the electric arc, because the current wave is distorted owing to the variability of the resistance. The Author gives a numerical example of such an arc illustrated by means of a diagram, and he states that the power-factor is 0.85. Another interesting example is that of a Cooper-Hewitt mercury-vapour rectifier. In this case not only is the current wave distorted but it is also displaced in phase; the displacement in phase causes a power-factor of 0.94, which is reduced to 0.931 by the distortion of the wave. In another example the electromotive-force wave is a true sine-curve, but the current curve is distorted, and, although in phase, the power-factor works out to 0.93. Pulsating continuous currents obtained from alternating currents by means of rectifiers are subject to the same laws, and the Author gives a numerical example (with diagram) of a rectified current from a single-phase mercury-vapour rectifier, charging a battery of storage-cells and having also a regulating rheostat in series.

H. R. S.

Calculation of Alternating-Current Transmission-Lines having Self-Induction and Capacity. A. BLONDEL.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 121, 161, 241, and 321.)

This Paper gives a long mathematical analysis in which the Author first develops the general equations for the calculation of the inductance and capacity of polyphase-current transmission-lines, and afterwards deals with particular cases. At the end of the Paper the Author shows how his formulas may be simplified by approximations in the ordinary cases occurring in practice.

W. C. H.

Electric Traction in the Simplon Tunnel. A. SOLIER.

(L'Éclairage Électrique, Paris, 1906, vol. xlviii, pp. 486-92, and vol. xlix, pp. 13-2.)

The Author has already described generally the equipment of the Simplon Tunnel for electric traction.¹ In the present Paper he gives details of the equipment of the generating-stations at Brigue and Iselle whence current is supplied to the line, and then describes the line-equipment, and the motors and other apparatus on the locomotives. The line is divided into five independent sections—from Brigue to the entrance of the tunnel, the northern half of the tunnel, the loop at the centre, the southern portion of the tunnel, and finally the line from the tunnel to Iselle. The rails are used for one of the phases in the 3-phase distribution, the wires for the other two phases being suspended, about 39 inches apart, from transverse wires of steel covered with a layer of copper to protect them from deterioration owing to the humidity of the tunnel. These transverse wires are fixed to bronze studs cemented to the tunnel-walls and are insulated at each end by pieces of porcelain fitted with an arrangement for tightening the wires. Each line-wire in the tunnel is doubled in order to give a larger surface of contact and to prevent too great a fall of pressure. The insulators carrying the line-wires are of special construction and can support a normal pressure of 18,000 volts. The tunnel is fitted with a door at each end to allow of ventilation by means of fans. These doors open and close by a vertical movement and are operated electrically. The special arrangements made on the electric line at these points to allow these doors to be closed are described by the Author. The second portion of this Paper gives a detailed description of the locomotives, which are similar to those used on the Valtellina line.

W. C. H.

¹ See Minutes of Proceedings Inst. C.E., vol. clxvi, p. 465.

Diagram of Electric Wave-Lengths. W. W. MASSIE.

(Electrical World, New York, 1906, vol. xlviii, pp. 330-1.)

In wireless-telegraphy investigations it is frequently necessary to determine electric wave-lengths with certain known capacity and inductance in circuit or to ascertain the capacity and inductance required to produce a certain wave-length. To avoid the necessity of making repeated calculations the Author gives in this Paper a diagram containing a series of curves from which the required values may at once be read off. The curves are based on the formula

$$\lambda^2 = KLC,$$

where λ = wave-length, L = inductance, C = capacity, and K is a constant having the value $4\pi^2V^2$, where V = velocity of light. For a given value of λ , therefore, the curve showing the relation between L and C is a rectangular hyperbola, and the diagram contains a series of such curves for values of λ between 100 metres and 1,000 metres, but the curves may be used outside this range for multiples or sub-multiples of these values of λ by altering in the proper manner the position of the decimal point in the values of the capacity and inductance.

W. C. H.

Wireless Telegraphy for Railways. EUGEN NESPER.

(Elektrotechnische Zeitschrift, Berlin, 27 September, 1906, pp. 906-10.)

This is a descriptive and analytical article on a series of tests carried out on the Marienfelde-Zossen and the Munich-Tutzing-Murnau Railways. It was found that communication could be maintained continuously and with certainty between a moving train and receiving apparatus as far as 12 kilometres (7.5 miles) distant. The transmitting-station is placed in a special carriage through the wheels of which it is earthed. The waves are sent off from an aerial conductor on the roof of the car and are transmitted along the adjoining telegraph-wires, which prevent them from scattering, to the aerial conductor at the receiving-station, which works in connection with the ordinary Morse instrument. The telegraph-wires may be as much as 50 metres (164 feet) distant before the working of the system is interfered with, while the normal function of the telegraph-wires is not influenced in any way.

The article is accompanied by a number of photographs and diagrams.

C. J. G.

Telegraphy in Iceland. C. E. KRARUP.

(Ingeniøren, Copenhagen, 1906, pp. 338-9.)

After many years' negotiations Iceland and the Faroe Islands are now connected by telegraph with the rest of Europe. The Danish Northern Telegraph Cable, laid from the Shetland Isles, is landed on the east coast at Seydisfjord; thence a land line, skirting the north coast and part of the west coast, runs about 380 miles (English) to the capital Reykjavik at the south-west corner of the island. A single steel wire would suffice for telegraphing, but for telephoning a second is added; both are bronze wires of 3 millimetres diameter (0.012 inch). They are carried on 14,000 poles, of which 25 per cent., impregnated with blue vitriol, were got from the Norwegian telegraph works at Namsos; the rest, impregnated with tar-oil, were from Collstrop in Horsens, Jutland, excepting a few hundred extra tall, which were supplied from the Danish government timber-preserving works at Sorø in Zealand. The holes in the ground for erecting them had in many places to be excavated by blasting. The bronze wires were from Altona, and were tested for the stipulated tensile strength of 61 kilograms per square millimetre (38.7 tons per square inch) and 64 per cent. conductivity. For crossing Hvalfjord (Whale Fjord) just north of Reykjavik, a 2-mile length of cable is laid, containing two copper wires of 5 square millimetres section (0.008 square inch), wrapped round with 0.5 millimetre (0.020 inch) iron wire, and covered with 8 millimetres thickness (0.032 inch) of gutta percha. The line was opened for use on the 1st October, 1906, and has worked satisfactorily. At first there were many breakages of the wires, consequent on the rough treatment they had undergone in conveyance through the rocky country; but owing to their hardness they did not get so badly scratched by dragging the coils along the ground. There are two short branches of iron wires, one to Eskefjord, near Seydisfjord, and the other to Vopnafjord. A somewhat complicated plan of switch-board is arranged for simplifying the combined control of telegraph and telephone, without requiring the employment of experienced attendants. It is explained in detail, and illustrated diagrammatically. Each of the telegraph stations is protected by an arrester of the kind employed by the Norwegian telegraph department, for rendering harmless the earth-currents associated with the terrestrial magnetism and the aurora borealis. Such phenomena were expected to occur very frequently in these regions, as has been already confirmed by experience. The cable is worked with Wheatstone apparatus, and the land line on the Morse system.

A. B.

Protection of Wooden Posts Carrying Electric Wires.

DE KERMOND.

(L'Électricien, Paris, 1906, vol. xxxii, pp. 230-4.)

Wooden posts carrying electric wires may be protected against decay by one or other of three processes:—(1) Artificial drying and protection from contact with the air by painting the surface; (2) Elimination of the sap by dilution or vaporization; (3) Impregnation with chemical substances forming insoluble compounds with the organic matters in the sap. The first two processes are sufficient when the pole is not thick and is easily got at for maintenance, provided it is not in contact with the soil; but for poles used for overhead electric wires, or for railway-sleepers, impregnation is the only satisfactory method of treatment. Starting with this explanation, the Author describes two systems of treatment. He refers first to the satisfactory results obtained by impregnating the wood with creosote under high pressure, but points out its disadvantages: penetrating odour and sweating of the liquid in the sun—rendering it unsuitable for use in populous districts. He then describes the Boucherie system in which a solution of copper sulphate is injected under pressure into the tree-trunk. Posts thus prepared have been shown by official tests in Germany to have a life of 13 years or 9 months, but the Author points out various disadvantages of this system, notably the necessity of impregnating the wood not less than 8 to 10 days after the tree is cut down, and also the fact that the life of the posts is affected by the nature of the soil in which they are fixed. A better process is the Kyan process, in which the wood is impregnated with mercuric chloride. The timber is simply plunged in a 2 to 3 per cent. solution of the salt contained in wooden or cement vessels, and is left to steep there for 10 to 15 days. No injection under pressure is necessary. The official German tests show that timber prepared by this process has a life of nearly 17 years; the creosoting process gives a life of 19 years 8 months but has the disadvantages pointed out above. For the Kyan process timber is not cut when in sap, but after that season is over; it must then be well dried and deprived of the bark before being immersed in the solution. The nature of the soil does not appear, up to the present, to have any effect on the life of posts thus prepared.

W. C. H.

Thermo-Electric Pyrometers. E. BALLOIS.

(L'Éclairage Électrique, Paris, 1906, vol. xlviii, pp. 372-6.)

This article is devoted to a description of some of the new pyrometers of the thermo-electric type and of recent modifications of earlier ones. The Carpentier pyrometer was discussed in the

earlier article,¹ but the Author now gives details of recent improvements in the specially-designed portable galvanometer used with it. For temperatures up to 1,600° C. the couple in this pyrometer is of platinum and platinum-iridium or platinum-rhodium, but for temperatures not exceeding 1,000° C. a more robust instrument is employed with a couple of iron (or copper) and constantan. The details of the arrangement of the couples in the Chauvin and Arnoux pyrometer for measuring temperatures up to 1,600° C. are next discussed. Finally the Author describes the construction of the Bristol pyrometer, made by the Weston Company, which uses couples of low resistance made of special alloys containing tungsten, steel, nickel, iron and copper. For precise measurements a special compensator is provided to keep the temperature of the cold junctions constant. This consists of a glass bulb, with a very narrow neck, containing mercury. Two platinum wires are soldered into opposite sides of the neck near the top and are connected by a thin platinum wire plunging into the mercury. As the temperature rises, the mercury expands and cuts out a portion of this resistance, thus compensating the drop in electromotive force of the couple due to rise of temperature of the cold junction.

W. C. H.

Electric Power in the Shops of the Pennsylvania Railroad Company. W. R. LOVELESS.

(Electrical World, New York, 1906, vol. xlviii, pp. 333-6.)

This Paper describes the installation and equipment for electric driving in the shops of the Pennsylvania Railroad Company, which are said by the Author to be among the largest and best-equipped railway-shops in the world. Belt-driving from the steam-engine has been almost entirely replaced by electric driving, there being now about 8,500 HP. of motors in service, while the steam-engine power driving machinery direct is less than one-tenth of that amount. There are five distinct groups of shops, and each has its power-plant, four of them being equipped with direct-current machines with a voltage of 230, while the fifth—the car-shop—has alternating-current plant generating at 2,200 volts. The Author describes the installation at each generating-station and the principal machine-tools used in each shop. Where new machines have been added to the shops, the individual drive has been generally adopted, but where steam has been replaced by electric driving, machines have to some extent been grouped together, the main shafting being divided into sections and belted to motors of the proper size, usually placed on overhead supports. At present there are four motors connected singly to machines for every motor driving a group. The

¹ See Minutes of Proceedings Inst. C.E., vol. clxvi, p. 467.

Author describes many of the principal machines installed and their motor-equipment. The largest motor is one of 80 HP., used on a 72-inch by 72-inch by 36-foot planer. Among the other heavier machines are two 90-inch wheel-lathes equipped with 30-HP. variable-speed motors, and six 90-inch lathes taking motors of 20 HP.; two large gang milling-machines, each driven by a 25-HP. and a 10-HP. motor, the larger motor driving the cutter-shaft while the smaller operates the feed; and, in the metal yard, a combination punch and shear driven by a 25-HP. compound-wound motor mounted on the machine and connected by chain-belt to the shaft. The pattern-shop contains numerous small machines—band-saws, circular saws, planers and lathes—each connected directly to a 5-HP. enclosed motor. In the foundry motors are used to drive casting-shakers, sand-shifters and mixers, and a belt system for conveying sand to bunkers above the moulding-machinery.

In the car-shops two-phase induction-motors, running at constant speed, are used. Speed variation is obtained by means of cone-pulleys or change of gears. The lumber-mill and cabinet-shop contain some heavy machines driven by separate motors, as, *e.g.*, a four-headed timber-planer which is belted to a 50-HP. motor, and a 4-inch band-saw for cutting timbers up to 12 inches in thickness, which is driven by a 30-HP. motor.

A complete record is kept of the history of each motor, generator and transformer.

W. C. H.

Launceston Hydraulic Power-Station.

A. MARTINEK and A. LAURI.

(*Elektrotechnische Zeitschrift*, Berlin, 19 July, 1906, pp. 672-7.)

This installation in Tasmania consists of five 500-HP. turbines direct-coupled to 400-kilowatt three-phase generators running at 500 revolutions per minute, and giving 5,200 volts with a frequency of 50 cycles.

The power-station is about 3 miles from the town itself, and is situated near the River Esk, from which the water is taken, first through a tunnel cut in the rock 850 metres (2,788 feet) long, and then through two riveted iron pipe-lines, each 62 metres (203 feet) long, 1.5 metre (4 feet 11 inches) in diameter at the top, and 1.2 metre (3 feet 11½ inches) in diameter at the bottom, to the main turbine supply-pipe, which is 1.85 metre (6 feet 1 inch) in diameter, and runs along the back of the power-house. Each turbine takes about 1,400 litres (49.4 cubic feet) of water per second under a total available head of 34.5 metres (113 feet). The speed is controlled by a sensitive governor acting on the turbine guide-blades through an hydraulic servomotor-cylinder, and a system of levers. By means of a small electric motor acting on the governor-

spindle through worm-gear, the speed of the turbines can be regulated from the switchboard.

The high-tension overhead power-line to the distributing transformer-station in the town is about 5 kilometres (3.1 miles) long, and is supported on porcelain insulators fixed to iron standards. The Esk Valley or Cañon being 90 metres (295 feet) wide at the point where the transmission-line crosses it, and it being impracticable to build a tower in the middle of the river, a wire cable made of silicium bronze, having a specially high tensile strength of 61.1 kilograms per square millimetre (87,000 lbs. per square inch) and of 45.36 square millimetres (0.07 square inch) section, was stretched between two strong iron towers on extra heavy insulators. The power-station being in a very inaccessible place for vehicular traffic a special wire ropeway was built over the river for the transport of machinery and goods, while a light suspension-bridge served for foot-passengers.

The overall efficiency of the plant at the official trials was found to be 75.2 per cent. at full load, the turbine and generator efficiencies being 80 and 94 per cent. respectively.

The article is accompanied by a number of illustrations and diagrams.

C. J. G.

Effect of Moisture on the Strength of Wood.

(Engineering and Mining Journal, New York, 10 November, 1906, p. 865.)

Very little being known about the influence of moisture on the strength of wood, the United States Forest Service has been making a thorough study of the question. The results of its investigations, as far as they have yet been published, are interesting and instructive. It has been found that the relation of moisture to strength follows a definite law. The strength of all kinds of wood increases rapidly with proper drying, the amount of increase depending on the species and the degree of dryness. Thus the strength of a piece of unseasoned red spruce may be increased over 400 per cent. by a thorough drying at the temperature of boiling water. But the strength decreases again as the wood re-absorbs moisture. Air-dried wood protected from the weather and containing 12 per cent. of moisture is, according to species, 1.7 to 2.4 times stronger than when green. Drying also increases the stiffness of wood. These conclusions have been drawn from pieces of small cross-section, not exceeding 4 × 4 inches. Large timber requires years of drying before the moisture is reduced to the point at which the strength begins to increase. It has been found that, under normal conditions, wood fibre will absorb a definite amount of moisture. Additional water only fills the pores. It has also been found that the water which simply fills the pores has no effect on the strength. The fibre saturation-point is:—for Longleaf pine 25, red spruce 31, chestnut 25, red gum 25, red fir 23, white ash 20.5, Norway pine

2 F 2

30 per cent., estimated on the dry weight of the wood. Wood which has been dried and re-soaked is slightly weaker than when green.

G. G. A.

Influences of Polishes on the Insulating Properties of Wood

CARL WERNICKE.

(*Elektrotechnische Zeitschrift*, Berlin, 17 May, 1906, pp. 471-2.)

As the result of a series of comparative tests on standard-pattern switch-handles, made of polished and unpolished walnut, the Author finds that even the most careful polish does not improve their insulating properties, unpolished being, therefore, quite as efficient as polished handles. A perfect polish is almost impossible, and always liable to deterioration from wear and tear and from atmospheric influences.

Further experiments in support of these conclusions were carried out on polished and unpolished wooden boards of different kinds, electric potentials up to 9,000 volts between sheets of tinfoil being used to cause failure in both sets of tests.

C. J. C.

Heath-Clay for Cement in Sea-Water.

(Ingénjören, Copenhagen, 1906, pp. 233-8 and 239-45.)

As an engineer of hydraulic works the Author draws attention to the utilization of the beds of "heath clay" in Denmark for the manufacture of cement. Natural irregularities in the quality of raw material have to be met by artificial mixtures, controlled by daily analysis. In sea-water, cement-mortar and concrete deteriorate under the chemical action of the clay contained in the cement sulphates contained in the water as well as in the cement itself. Mr. H. Le Chatelier states that all depends on having a cement containing silicic acid and clay, together in excess of lime, but with clay less than the acid and preferably replaced by compounds of iron: he recommends adding trass finely ground, in quantity equal to the cement; and avoiding sulphuric acid in any form, and combines with aluminates of lime and causes destruction. In order to explain how best to counteract the dangerous calcium-sulphate aluminates, which causes the cement to become soft in sea-water, the Author considers the subject in three sections: (1) sulphuric acid naturally contained in the concrete; (2) penetration of sea-water into the concrete; and (3) freedom of the cement from cl

(1) From the natural sulphates found in the raw lime and clay it is practically impossible to free the cement; but these ingredients should contain the minimum of sulphuric acid, without addition of gypsum (hydrated sulphate of lime). For general use there is no harm in adding a little gypsum, because it renders the cement slower in setting, and consequently more convenient to work with. The same end is attained without any gypsum, by adding water, whereby in some measure the time of setting can be prolonged, wherever quick setting is an inconvenience.

(2) The sulphates of magnesia and lime in sea-water must be prevented from penetrating into the masonry by making the mortar as stiff as possible, filling up the interstices of the sand with cement. Sometimes the concrete is faced with dressed stones, paving-stones, or clinker; or else the outside layer of cement is mixed richer. Even if only in the joints, the mortar is exposed to the action of the sea-water, and should be made as dense as possible by using cement liberally. About ten years ago the Author carried out, for the Scandinavian Association of Portland Cement Makers, a series of investigations with home and foreign cements, partly in the laboratory with experimental test-bars, and partly with concrete blocks in one of the groynes close to the Thyborøn Canal,¹ including some blocks mixed with trass and others with heath-clay. These experiments are here reviewed, and are critically examined in detail at considerable length. As the heath-clay blocks were free from internal deterioration, it is hoped this material may be used for mixing with cement. There is much in its favour as compared with trass. In the latter only 15 to 20 per cent. of the silicic acid it contains is useful; whereas of that formed organically in heath-clay the whole is reckoned to be utilized, amounting to about 70 per cent., so that a smaller weight of clay suffices chemically; and the fact of its being naturally so fine a powder is in favour of its purely mechanical action of filling up the pores in the cement.

(3) The most difficult matter for preventing the permanent and destructive formation of calcium-sulphur-aluminate is to avoid aluminium in the cement. It can be got rid of only by not mixing the cement with chalk and clay proper, but with a material poor in clay and rich in silicic acid: these conditions are found in heath-clay. This section of the subject is dealt with at great length, including analyses of the clay, method of treatment, admixture of gypsum, duration of setting, and results from testing of specimens. The main recommendations for guarding against the calcium-sulphur-aluminate are that the Portland cement should be burnt to clinker from a careful mixture of lime and silicates, with only so much iron oxide and alumina as may be necessary for clinkering. For these two ingredients, as well as for any others that may possibly be met with, the maker should guarantee a maximum percentage which shall not be exceeded. After burning, nothing should be added to the cement except the water needed for regulating the time of

¹ See Minutes of Proceedings Inst. C.E., vol. clix, p. 400.

setting; a statement of the quantity necessary should accompany every consignment. The proportions for mixing the concrete should be specified in weight of cement and in dry measure of air-dried heath-clay and sand and shingle; if granite chips take the place of shingle, one-seventh less will be the quantity. The shingle and heath-clay should first be mixed dry in a trommel fitted with a revolution-counter, until the clay is finely divided. Then the cement and sand should be added, and last of all a measured quantity of fresh water. Each of these mixings should undergo a certain number of revolutions, which is fixed for every mixer, and may have to be varied according to the natural condition of the materials.

Mr. Foss said it must be determined experimentally how much heath-clay can be substituted for trass as an admixture in hydraulic cement. But he denies that cement can be mixed and burnt with lime and silicic acid alone. It is not possible to make Portland cement without clay; a certain quantity of sesquioxides of iron and of aluminium is required. To some extent red oxide of iron satisfies the requirements of a flux; Mr. Le Chatelier proposes it as an ingredient for a cement that will be proof against sea-water. Mr. Foss has made a cement of finely-ground quartz and lime with sesquioxide of iron added as a flux, and it has proved successful in all respects, excepting only the length of time it took for setting, which was not less than fourteen days in the laboratory; after a month it was excellent. Its composition was: silica 24·7 per cent., sesquioxide of aluminium 1·8; sesquioxide of iron 5·1; lime 67·4; residue 0·5 per cent. There is thus 6·9 per cent. sesquioxides of iron as a flux. Hitherto he has himself chosen a heath-clay from Silstrup containing 24·1 per cent. silicic acid, 4·5 clay-earth, 4·5 sesquioxide of iron, and 65 per cent. lime. With chalk this makes a thorough normal Portland cement. The time of setting cannot be controlled by using water instead of gypsum (hydrated sulphate of lime); the latter is essential, averaging 1·6 per cent. and ranging between 1 and $\frac{1}{2}$ per cent.

Professor Teller, having planned the sluices at Kalvebodstrand and recommended trass-cement mortar for the concrete, said that adoption had been determined by its cheapness. The contractors tendering were allowed their choice of cement mortar with or without trass. A mixture of 1 cement, 1 trass, $4\frac{1}{2}$ sand, and 10 chips was as strong under test as a mixture of 1 cement, 3 sand, and $5\frac{1}{2}$ chips; and of these two mixtures, that containing the trass, though an unknown material, was tendered for at a much lower figure.

Professor Hannover has no doubt that heath-clay can be used to make strong cement-mortar, although no experiments have yet been made thereon in the government testing-establishment. But more have been made there with heath-clay in lime-mortar, whereby the quantity of lime needed is diminished, and mortar is obtained of great strength. The reason is that in the heath-clay the silicic acid is in a form which is more easily attacked than sand. The li-

mortar experiments furnish ground for believing that in cement-mortar also the heath-clay will give a strong cement, and there is good reason to expect that it will prove as effective in sea-water as trass. Instead of heath-clay, which is so impure, trials are about to be made of a silicious tufa obtained from the Caucasus, where it is found as a white rock.

The Author stated that the composition of two samples of cement, which he got burnt in Aalborg, was respectively 61.8 and 66.3 per cent. lime, 30.4 and 26.7 silica, and 6.9 and 6.0 per cent. sesquioxides. There was remarkably little iron in the trial burnings, because the heath-clay used contained no iron. But it was no good to think of preparing large quantities of a cement consisting only of chemically pure lime, silicic acid, and iron oxide, because the raw materials were too dear to buy and too difficult to deal with. A meagre heath-clay must be used, with which would be some clay-earth. He has applied to the Clay Laboratory for further information about different kinds of heath-clay, and for more analyses than those published. Also a general map, however rough, of the properties already taken up would be of interest and importance; he has had much difficulty in finding out where the different kinds of heath-clay come from. Instead of getting from the Caucasus a material which is perhaps of somewhat finer grain, he thinks the clay might be washed out of the Danish earth.

Mr. Fischer-Møller said he had no more analyses than those which had been published. The silicious tufa cannot be washed out of the heath-clay; these two materials cannot be separated from each other in a mechanical way. In heath-clay generally there is not so much as 70 per cent. soluble silicic acid, nor so little clay as would then be left. He wonders whether the heath-clay used by the Author may not have been some that had been very thoroughly weathered. In general, when the heath-clay is dug fresh from its bed, it is not so easy to pulverize; but on Svalklit (Cool Down) and at many other places, where large masses have slipped, they lie as a tolerably loose powder. Such heath-clay is easy to deal with, particularly after it has undergone a winter's freezing.

A. B.

Experiments on the Permeability of Cement Mortars to Water under Pressure. JOSEPH W. ELLMS.

(Engineering Record, New York, 27 October, 1906, pp. 467-8.)

The materials tested were six various mixtures of Portland and natural cement, river sand (quartz), and limestone screenings and dust, with 10 to 17 per cent. water. The forms were 3-inch cubes and the cylinders were 8 inches long and 6 inches in diameter, the thickness passed through by the water being $1\frac{1}{2}$ inch. The duration of the first experiment was 1 day in air and 6 days in water.

Tables are given showing results in seepage in gallons per hour per square foot, under pressure of 50 lbs. per square inch. Further experiments with older specimens, 1 day in air and 27 days in water, and with varying pressures of 15 to 30 lbs. were made, and the results were tabulated. The methods of testing are explained.

The conclusions may be summarized as under:—

- (1) No mortar is impervious if under sufficient pressure.
- (2) Permeability decreases with age.
- (3) Permeability is more dependent on the compacting than on any other factor.
- (4) Continuous filtration decreases permeability.
- (5) Rich mortars are most impermeable.
- (6) Mortars mixed dry are more permeable than those mixed wet, but the difference diminishes the longer the dry mixture is subjected to continuous filtration.
- (7) The more thoroughly the materials are mixed, the less permeable the mortar becomes.

C. O. B.

Direct Portrayal of the Neutral Axis. OTTO HÖNIGSBERG.

(Ingeniøren, Copenhagen, 1906, pp. 373-3.)

As long ago as 1815 Brewster discovered that transparent bodies became doubly refracting when subjected to mechanical stress. On bending a transparent substance, which is illuminated by two prisms, of which the directions of polarization cross each other, the field of light is generally brightened; but in places where there is no stress, the illumination remains unaffected and consequently looks dark. Mesnager has observed the neutral axis in the mere bending of a body resting on two supports under a load. Independently the Author has now carried these investigations further, using glass specimens of horse-shoe or crank-axle form, and substituting circular polarization for plane polarization. The portions which then remain dark in all positions indicate the neutral axis. Two photographs are reproduced of results thus portrayed.

A. B.

Ultra-Microscope. L. MICHAELIS.

(Ingeniøren, Copenhagen, 1906, pp. 273-7.)

The smallest object that can be seen in an ordinary microscope has been not less than one two-thousandth of a millimetre (say one fifty-thousandth of an inch). The ultra-microscope shows objects that are no larger than one four-millionth of a millimetre (say one hundred-millionth of an inch). In the illuminated field of a microscope the

smallest object visible is seen as a dark particle on a bright background, and is rendered visible only by intercepting the light. It is calculated therefore by Helmholtz and Abbe that objects smaller than half the length of a wave of light may fail to intercept the waves, and may thus remain invisible, however high the magnifying power. Richard Zsigmondy observed that, although glass, made ruby red by a slight admixture of gold, may be got perfectly transparent, yet no trace could be detected microscopically of the gold particles it contains. But if now the glass be illuminated by a beam of sunlight concentrated thereon through a lens, a luminous cone appears in it, just as in water that is charged with particles of dust, or as in the dusty air of a room when in sunshine. He argued therefore that, if the gold particles in the glass could be rendered self-luminous, they would thereby become visible. This has been accomplished by an arrangement enabling the luminous cone to be viewed from the side, instead of the eye facing the light: the sun's rays are made to fall on the glass at right angles to the axis of the microscope, and the luminous cone then shows the gold particles shining in it, like stars on a dark background. The apparatus devised successfully for this purpose by Karl Siedentopf at the Zeiss laboratory is described in detail with the aid of an illustration; and an account is given of observations made by this means, particularly in physical and chemical research.

A. B.

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I N D E X

TO THE

MINUTES OF PROCEEDINGS,

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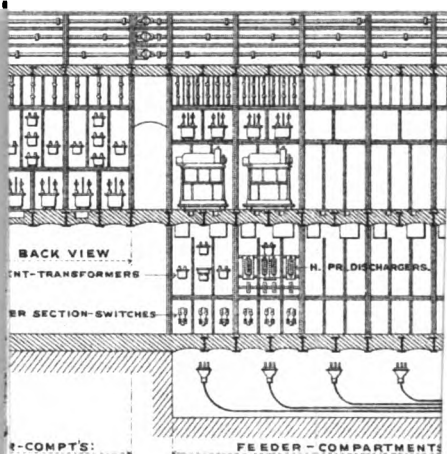
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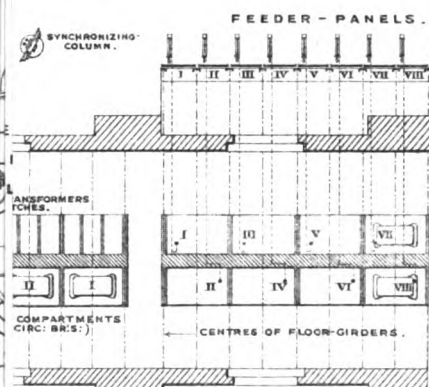
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DUKE STREET, STAMFORD STREET, S.E., AND GREAT WINDMILL STREET, W.

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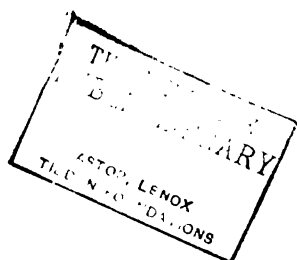


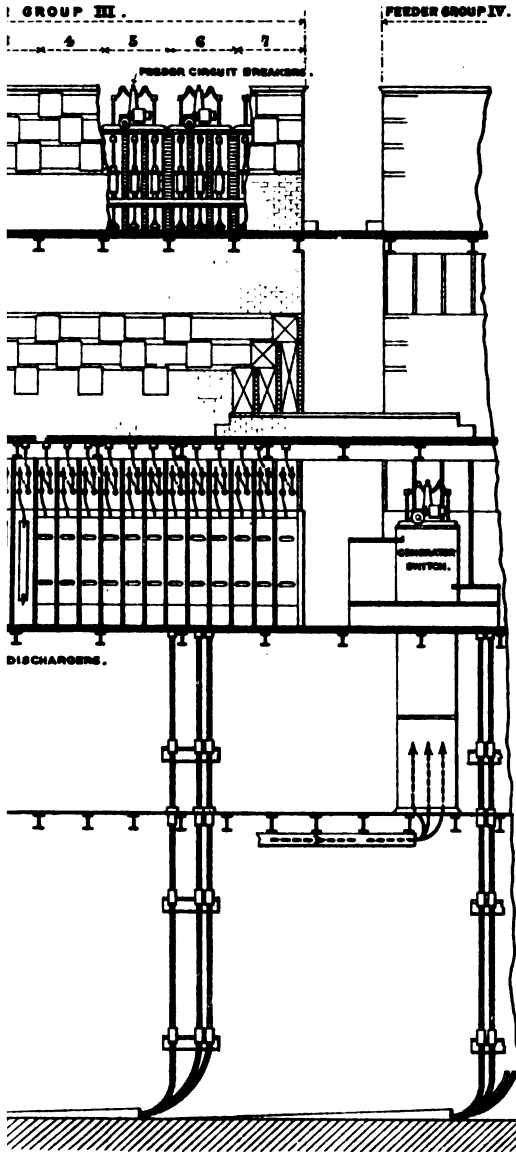
SECTIONAL ELEVATION



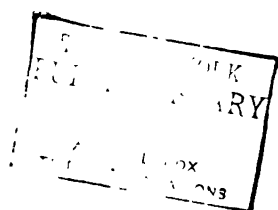
LTS, 3000-KILOWATT UNITS)

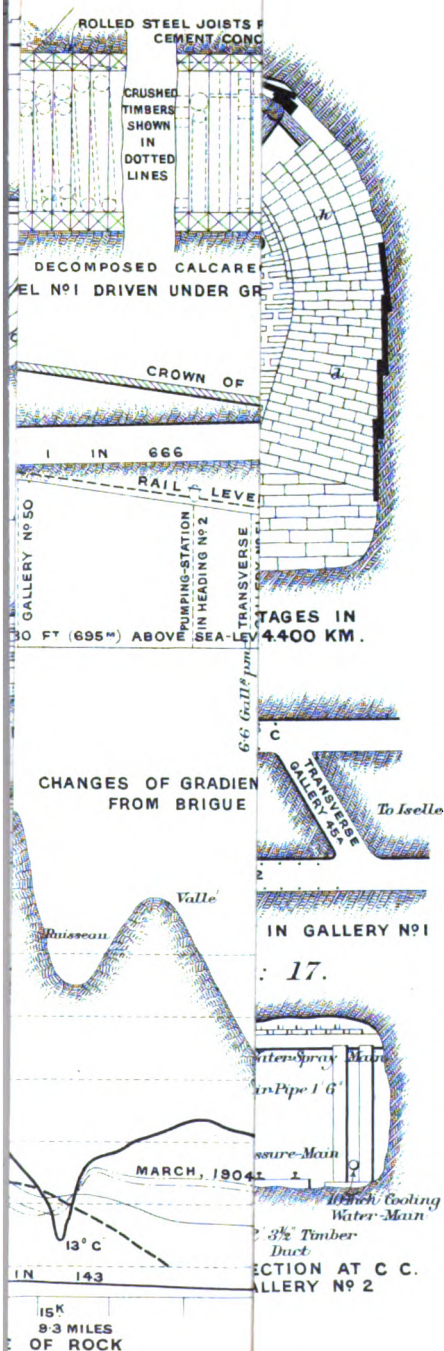
ON, GLASGOW.





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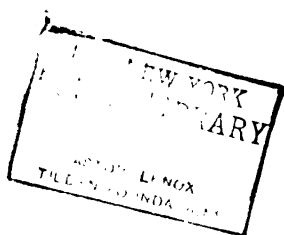
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